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DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Technical Report 1710-TR

IMPROVISED SHAPED CHARGES WITH PASTE EXPLOSIVE FILLER

Task 8F07-10-002-02

19 March 1962

NOX

U. S. Army Engineer Research And Development Laboratories

FORT BELVOIR, VIRGINIA

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
CORPS OF ENGINEERS

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PREFACE

The investigation covered in this report was conducted under the authority of Task 8F07-10-002-02, "Demolition Material and Equipment" (formerly Project 8F07-10-002). A copy of the project card is included as Appendix A.

Tests covered herein were performed during November and December 1960 at the Engineer Proving Ground, Fort Belvoir, Virginia.

The investigation was conducted by James A. Dennis, under the general supervision of B. F. Rinehart, Chief, Demolitions Section, Demolitions and Fortifications Branch. All test firings were conducted by Jesse M. Tyson and Bert Sheets of the Mine Warfare and Barrier Branch Test Unit. Richard Deighton of the Data Processing and Statistical Services Branch made the statistical analyses. Improvised components of the shaped charges were fabricated by the Metal Working Shop, U. S. Army Engineer Research and Development Laboratories, and the machined shaped charge cones were manufactured by Firestone Tire and Rubber Company, Defense Research Division, Akron, Ohio.

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SUMMARY

This report covers tests conducted to determine the effectiveness of RDX base paste explosive as the explosive filler for improvised shaped charges. The performance of hand-formed and precision manufactured cavity liners was also evaluated.

The shaped charge parameters investigated were: Type of explosive filler, explosive loaded height above liner vertex, type of conical liner, and standoff distance.

The tests performed were designed as a full factorial experiment, and the results were analyzed by the analysis of variance. Seventy-four improvised shaped charges were fabricated in the field and fired into a target stack of steel plates. Measurements were recorded of the depths of penetration and volumes of the resulting holes in the target. A controlled comparison was made of the shaped charges loaded with Composition C-4 and shaped charges loaded with paste as well as the other charge variables tested.

The report concludes that:

a. Paste explosive is an effective explosive filler for improvised shaped charges.

b. Precision manufactured shaped charge liners produce greater and more reliable yields than hand-formed liners, but hand-formed liners afford yields acceptable for general demolition tasks requiring the use of shaped charges.

c. For improvised shaped charges, paste explosive is almost as good as Composition C-4 explosive in most qualities and better in ease of loading; other military explosives being solid are not readily adaptable to improvised shaped charges.

d. Field fabrication and use of improvised shaped charges is feasible.

e. Additional borehole penetration tests should be conducted in various materials, especially concrete and asphaltic pavements, to obtain complete data relative to the usefulness of improvised shaped charges.

IMPROVISED SHAPED CHARGES WITH PASTE EXPLOSIVE FILLER

I. INTRODUCTION

1. Subject. This report covers tests conducted to evaluate the effectiveness of paste explosive as the explosive filler for improvised shaped charges. Composition C-4 plastic explosive was used in comparative testing with paste explosive, with the concurrent comparative testing of hand-formed and machined cones as cavity liners.

2. Definitions:

a. The term "shaped charges" generally identifies a high explosive charge having a conical or linear cavity lined with a suitable material that concentrates the explosive energy to produce deep holes or cuts in a target against which it is exploded.

b. The "jet" from a lined conical shaped charge is the slender, high-velocity stream of gases and liner particles which are accelerated out of the open end of the lined cavity after detonation of the charge.

c. The "jet tip" is the end of the jet which moves fastest and strikes the target first. It is formed from particles of the liner cone at or near the cone apex.

d. The "slug" is the massive and relatively slow moving remnant of the collapsed metal liner as distinguished from the jet.

3. Background and Previous Investigation. During November 1957, the U. S. Army Engineer Research and Development Laboratories (USAERDL) conducted tests to determine the feasibility of field fabrication of a shaped charge with the capability of penetrating 6 inches or more of armor plate.[1] Experiments were conducted by using a statistical design which employed three levels of each of the shaped charge variables cone angle, height of explosive above cone vertex, standoff distance from base of charge to target, and thickness of the charge cavity liner. The other variables inherent in shaped charge design were held constant. Among the conclusions formed as a result of the investigation are the following:

a. Field fabrication of a shaped charge capable of penetrating 11 to 13 inches of armor plate is feasible.

1. Howard J. Vandersluis, Improvised Shaped Charges, Interim Report, USAERDL. Fort Belvoir, Virginia, 4 April 1958.

b. Optimum design characteristics for a 3-pound shaped charge are a 50-degree-angle, 1/8-inch-thick, $3\frac{1}{2}$-inch-base-diameter, copper conical liner placed in a 4-inch steel cylinder loaded with C-4 explosive to a height of $2\frac{1}{2}$ inches above cone vertex. The charge should be detonated at a $5\frac{1}{4}$- to 7-inch standoff distance from the target.

c. Use of boosters increases the effectiveness of shaped charges, but the welding of the joints of hand-formed cones does not significantly affect the depth of penetration.

In 1958, as recommended by Interim Report, "Improvised Shaped Charges,"[2] USAERDL conducted additional studies to evaluate the performance of improvised shaped charges.[3] Tests were performed in which the explosive weight was reduced both by decreasing the charge diameter and by tapering the charge top. Although these methods resulted in a 15- to 50-percent charge-weight reduction, the penetrations made in mild steel were generally inconsistent, and difficulty was experienced in loading tapered charges. One series of tests was performed with cones of aluminum alloy, lead-tin alloy, and lead-antimony alloy; the use of laminated cones as shaped charge liners was also studied. Based on limited test data, the alloy and laminated metal cones were about 50 percent as effective as 1/8-inch-thick copper cones of like apex angle.

When a shaped cavity is made at one end of a high explosive charge and the charge is detonated with the cavity facing the target, part of the explosive force is formed into a jet along the cavity axis and the destructive power of the explosive is focused at a point. The discovery of this "jet effect" of shaped explosive charges is credited to Charles E. Munroe, who announced his observation of the phenomenon in 1888; hence, the shaped charge principle is generally referred to as the "Munroe effect."

Although the discovery of the shaped charge effect was formally announced in 1888, the usefulness of the metallic liner was not recognized until as late as 1936. Credit for this discovery is generally accorded to Dr. R. W. Wood, who found that a metal liner of a cavity in an explosive charge produced high-velocity fragments. In 1940, the Swiss inventor Henry Mohaupt and a Major Delalande introduced steel-lined conical-cavity charges to the U. S. Army. About 1941, a research and development program concerned with the lined-cavity effect was started in this country. Thus, the term "shaped charge," which was coined during World War II, generally

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2. Ibid.

3. George T. Mahler, Improvised Shaped Charges, Second Interim Report, USAERDL, Fort Belvoir, Virginia, 4 March 1959.

implies the presence of a lined cavity in an explosive charge. The cavity liner may be aluminum, copper, steel, or glass, but copper is the most commonly used liner material.

A variety of shapes have been used for explosive charge cavities. Hemispheres, cones, paraboloids, and trumpet and helmet shapes have all been tried, some of these giving better results than others. However, conical lined cavities have been used most frequently for penetration purposes and have been most thoroughly investigated.

The phenomenon of shaped charge effect can be simply described in the following manner: After initiation at the charge end opposite the cavity, the detonation shock wave travels through the explosive charge. As the shock wave progresses through the charge and reaches the cavity, the explosive forces which act with equal forces in all directions will have a resultant force normal to the cavity surface working progressively down from its apex. If the cavity is symmetrical about the axis of the charge, these forces will meet at the axis concentrating in a jet the energy which in a flat charge would be spread over the whole area. When a metal liner is present, the liner collapses and forms a jet stream of high-velocity gases and metal particles capable of penetrating a considerable depth of steel, concrete, earth, rock, and the like (Fig. 1). Although jets from metal liners are known to require some distance to form and persist for 60 to 300 feet, as the jet lengthens it has the tendency to waver and break up with a resulting decrease in penetration. Thus, a given design of shaped charge requires an optimum standoff from the target to be most effective.

Many studies have been made of the civilian and military applications of the shaped charge effect since its discovery. Most of the military applications considered have been mainly concerned with projectiles and manufactured demolition charges using the shaped charge principle. Little experimental study has been devoted to determining the feasibility of field fabrication and use of improvised shaped charges by combat forces.

Two standard shaped charges, the M2A3 and the M3, having limited ranges of capability are available to U. S. Forces. The 40-pound M3 shaped charge is capable of penetrating 60 inches in concrete, 20 inches in armor, and about 8 feet in earth.[4] Field Manual 5-25 states that the 15-pound M2A3 shaped charge will penetrate 36 inches in concrete, 12 inches in armor, and about 5 feet in earth. Since there is no positive method of varying the firing

4. John W. Barnes, Experimental Uses of the Charge, Shaped, 40-lb, M3, Report 994, The Engineer Board, Fort Belvoir, Virginia, 5 March 1947.

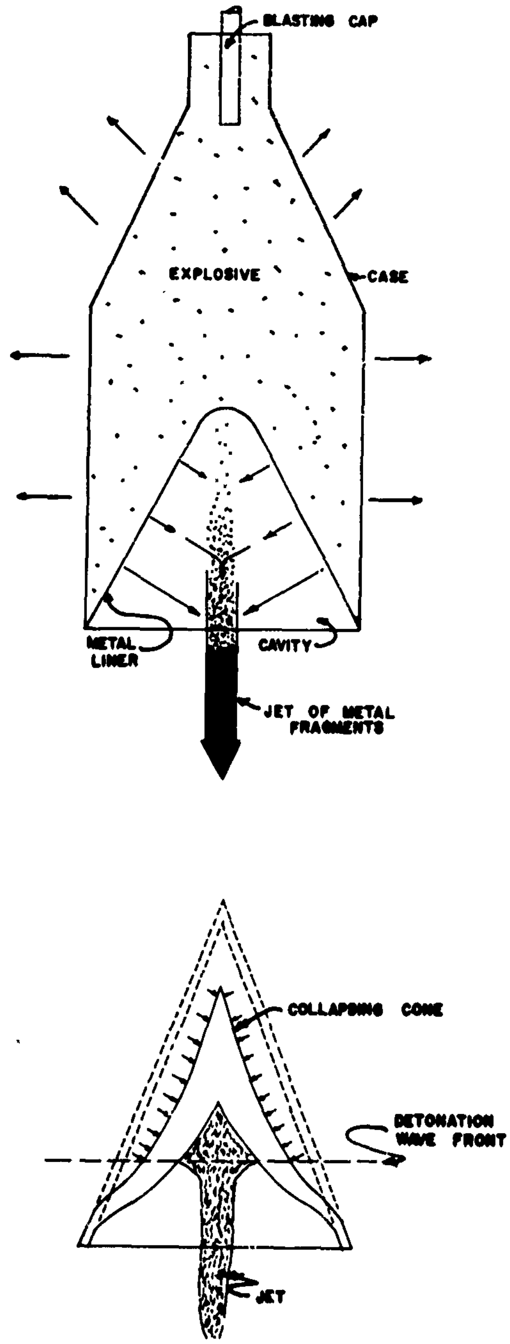


Fig. 1. Mechanism of formation of shaped charge jet.

procedure to obtain given results, troops are greatly handicapped if the demolition mission requires results which are below, between, or beyond the capabilities of the standard shaped charges. Consequently, U. S. Forces appear to have a requirement for instructions describing design, fabrication, and use of shaped charges. The availability of these data would give troops the capability to fabricate shaped charges to fit any demolition mission requirement.

II. INVESTIGATION

4. Description of the Problem. The objective of these tests was twofold: first, the evaluation of paste explosive as an explosive filler for improvised charges, and second, the comparison of the performance of hand-formed and precision manufactured cones. Because many variables affect shaped charge performance and testing of all was not feasible, four of the more important variables were selected for evaluation. These variables were: Type of explosive, height of explosive above cone vertex, type of cone, and standoff distance of the charge from the target. Composition C-4 explosive was used as a control to provide a basis for evaluation of the performance of paste explosive. The two explosives were each loaded behind $3\frac{1}{2}$-inch-diameter cones to a height of 1-3/4 and 2-1/2 inches above the cone vertices of the two cone types, hand-formed and machined. The assembled charges were fired at standoff distances of 5 and 9 inches from the target, a stack of steel plates. Both depth of penetration and volume of hole were selected as measures of yield for the charges.

5. Description of the Charges. Charges were fabricated with both hand-formed and machined cones and loaded with Composition C-4 explosive, some to 1-3/4 and some to 2-1/2 inches above the cone vertices. Likewise, charges were fabricated with both hand-formed and machined cones and loaded with paste explosive to each height of 1-3/4 and 2-1/2 inches above cone vertices (Fig. 2). The charge assembly consisting of a copper cone, sheet metal casing, explosive charge, and booster was fabricated and assembled as follows:

a. Copper Cavity Liners. Half of the copper conical liners were formed as shown in Figs. 3 through 6. The liners were cut from 1/8-inch-thick sheet copper, formed around a steel mandrel with a rubber-faced hammer, and then welded at the joint. The apex of the cone was cut off to the correct height, and the resulting hole was filled with a copper plug and welded. This resulted in a truncated cone which was sanded to obtain maximum uniformity. Finished hand-formed cones were 1/8 inch thick, 3-1/2 inches in diameter at the base, and had 60-degree vertex angles (Fig. 6). These locally improvised cones were of uneven quality.

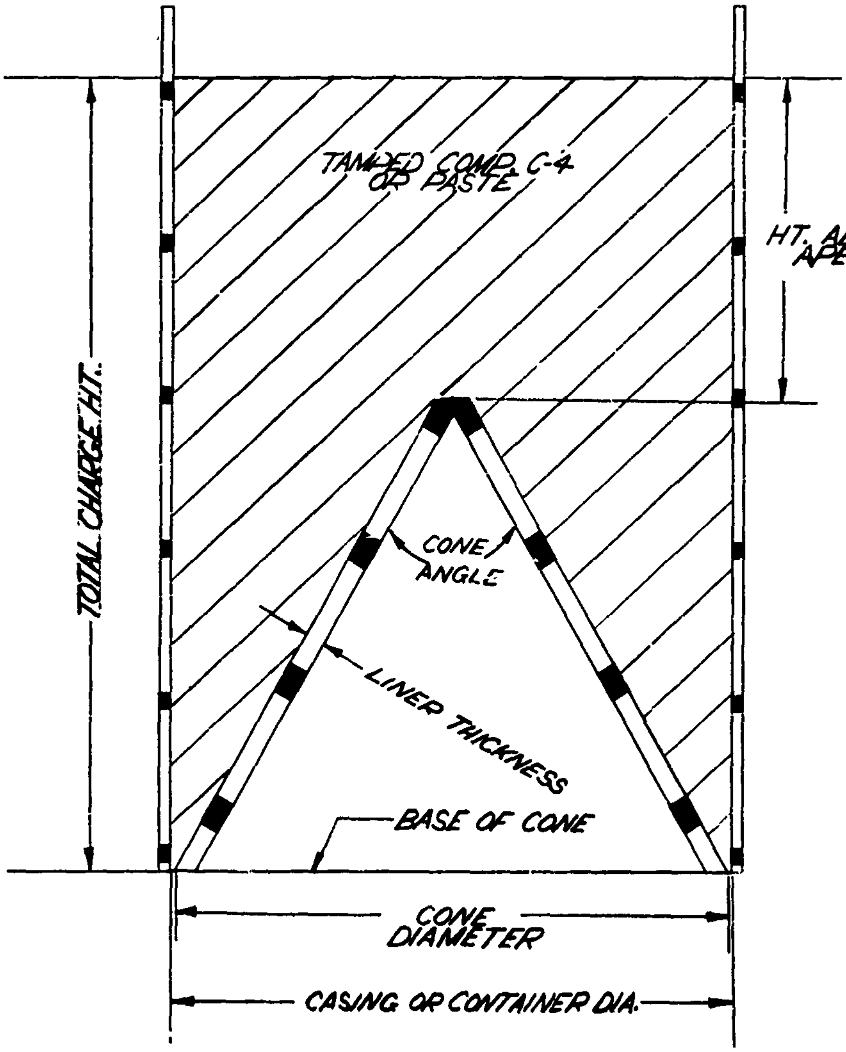
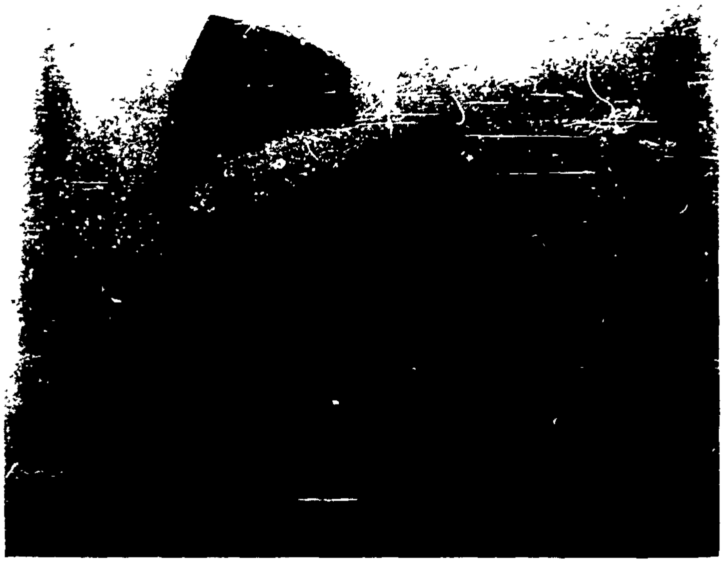


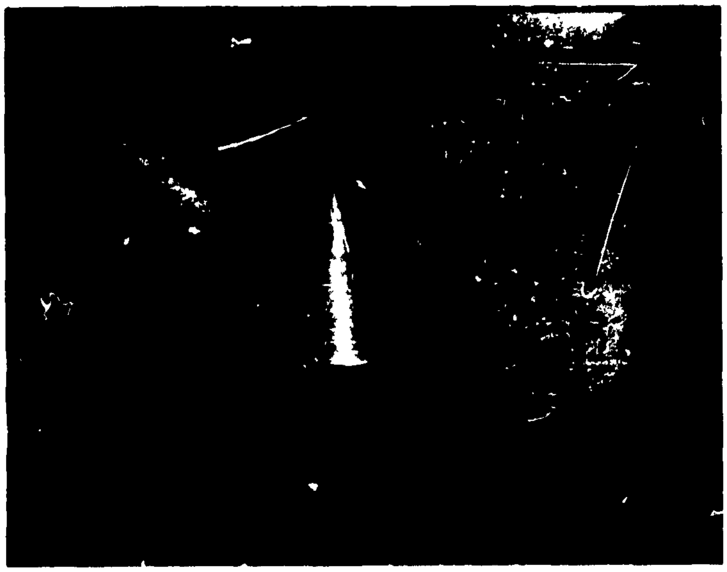
Fig. 2. Cross-sectional view of a hand-tamped, improvised shaped charge.

The other half of the copper liners were manufactured by a spin process at Firestone Tire and Rubber Company, Defense Research Division. Like the hand-formed cones, these truncated cones were 1/8 inch thick, 3-1/2 inches in base diameter, and had 60-degree vertex angles, but they were precision manufactured to closer tolerances than was possible with the hand-formed cones (Fig. 6).



E5025

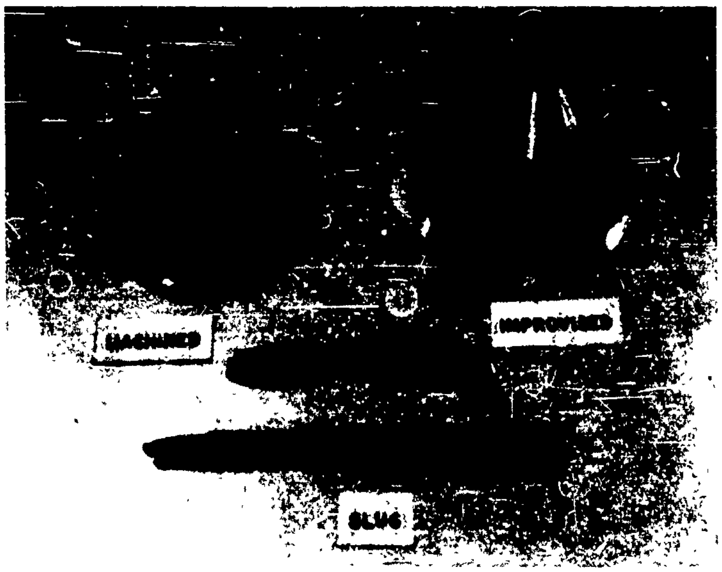
Fig. 3. Conical liner being cut from sheet copper.



E5026

Fig. 4. Conical liner being formed around steel mandrel.

E5028
Fig. 5. Apex and joint of conical liner being welded.



H1069
Fig. 6. Machined and improvised conical liners and slugs resulting from liner collapse.

b. Charge Casing. A 4-inch-diameter, 21-gage sheet metal cylinder was used as the casing for the explosive charge and the cavity liner (Fig. 7). One end of the casing was sealed with masking tape, and the conical liner was placed within the casing with the base on the masking tape. The liners were centered in the casings and secured just before the charges were loaded.

E5020

Fig. 7. Sheet metal casing with standoff legs and conical liner.

c. Explosive Filler. Composition C-4 and paste explosives were used as the explosive fillers for the charges. The chemical compositions of the two explosives are shown in Table I. The explosives were loaded into the containers by hand-tamping (Figs. 8 and 9). Composition C-4 charges were loaded to heights of 1-3/4 and 2-1/2 inches above cone vertices. The paste explosive charges, however, were loaded according to weight; that is, the amount of explosive loaded in each type paste charge was equal to the average weight of explosive that was loaded into the similar type C-4 charge. Since the improvised and the manufactured cones required different weights of C-4 for a given loading height, a different weight was required for each vertex level and cone type in the paste charges.

Table I. Chemical Compositions of C-4 and Paste Explosives

Composition	C-4 Explosive	Paste Explosive
RDX (percent)	91.00	76.44
DNT (percent)	-	4.89
MNT (percent)	-	3.26
Polyisobutylene (percent)	2.10	1.74
Motor oil (percent)	1.60	1.36
Di-(2-ethyl) hexyl sebacate (percent)	5.30	4.46
Tween (percent)	-	7.85
Total	100.00	100.00

E4179

Fig. 8. Composition C-4 explosive being hand-tamped into an improvised shaped charge.

d. Charge Loading Procedure. All charges were loaded carefully in order to obtain maximum explosive density. Care was taken to insure the explosive was homogeneous with minimum air cavities and that the explosive was in good contact with the liner. It has been shown that unless these conditions are attained, the collapse of the liner is not uniform and the asymmetric jet formed will have poor penetrating properties. Masking tape was placed over one end of the container, and the cone, centered in the cylinder, was held in place by the tape during loading. The

H1073

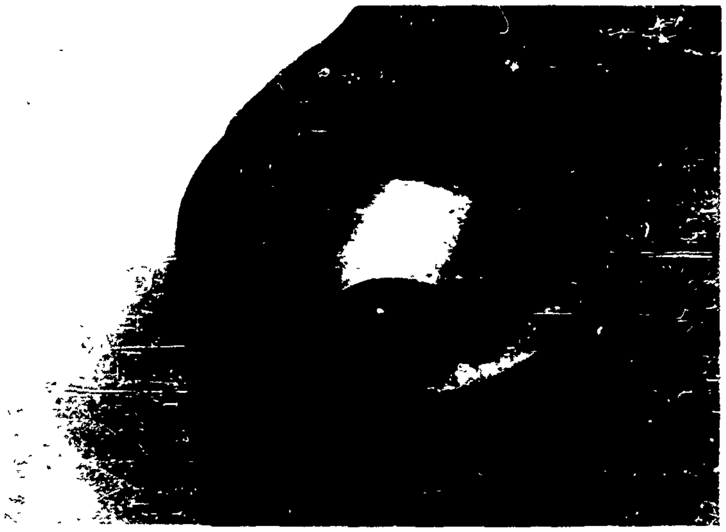
Fig. 9. Paste explosive being worked into an improvised shaped charge. Note apex of conical liner protruding from explosive filler.

$3\frac{1}{2}$-inch-base-diameter cones were centered in the 4-inch-diameter container so that a $\frac{1}{4}$-inch explosive flange was formed around the cone base. Previous test results had indicated that such an arrangement gave optimum results.[5]

Composition C-4 charges were loaded by rolling small amounts of explosive into thin fingers and placing these fingers into the container one at a time. As each finger of explosive was placed in the container, it was tamped to maximum density with a wooden tamping stick. Additional small increments of explosive were added and tamped into the container until the desired height above the vertex was reached (either 1-3/4 or 2-1/2 inches). A 15-gram PETN booster was embedded in the top center of each charge to insure high-order detonation (Fig. 10). Paste explosive charges were loaded in a manner similar to that for the C-4 charges; however, hand-tamping was not required because the oily explosive could not be compacted. Instead, the paste was worked with a tamping stick to eliminate as many oil pockets as possible. The specified amount of paste explosive was loaded into the containers in small increments, and the top of the explosive column was then

5. Vandersluis, op. cit.

leveled with a spoon. The 15-gram PETN boosters were placed in the paste explosive just before the charges were fired to prevent desensitization of the booster by absorption of oil.



F6731

Fig. 10. Fifteen-gram booster being embedded in top center of shaped charge explosive filler.

G9768

Fig. 11. Improvised shaped charge being X-rayed to determine air cavities and low-density areas in explosive filler.

Because the loaded paste charges were thought to contain air cavities and low-density areas, all paste charges were X-rayed (Fig. 11). Radiation technicians examined the X-rays closely and concluded that the paste charges contained no air cavities, though low-density areas were apparent (Fig. 12).

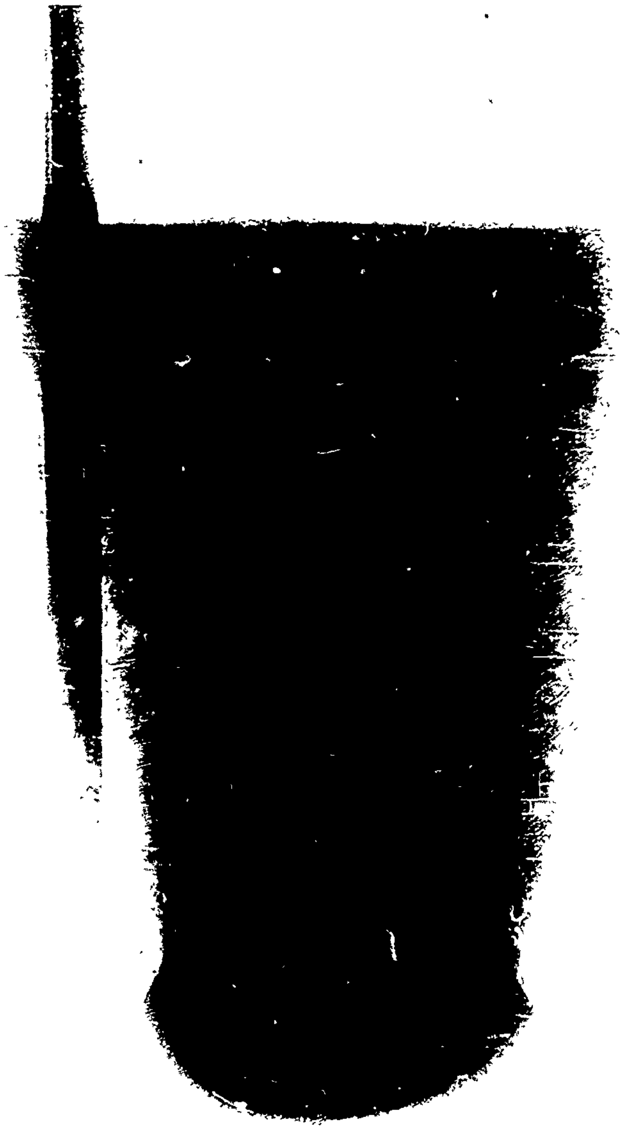
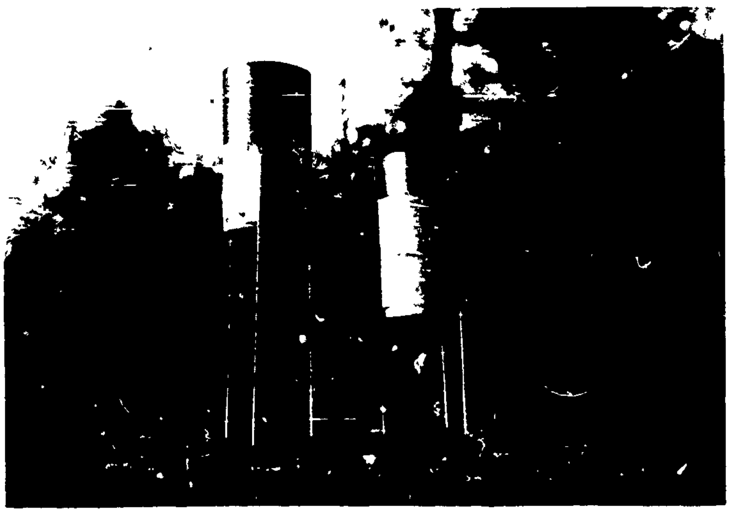


Fig. 12. X-ray photograph of a paste explosive shaped charge.

The C-4 and paste charges were loaded in random order to minimize bias due to extraneous factors. The same demolition testman loaded all charges during a period of 6 days, using explosive with the same lot number throughout the loading.

e. Density Determination. Twelve charges loaded with C-4 and twelve with paste were tested for density of the explosive. The charge container with attached liner was waterproofed at the liner end. Water was poured from a graduated beaker into the charge container to the specified height for the explosive column, and the amount of water used was recorded. After the water was emptied from the charge container, the explosive sample was loaded into the container to the same level as that for the water. By dividing the mass weight by the volume, the average densities for the C-4 and paste charges were determined to be 1.57 and 1.52 grams per cubic centimeter, respectively.

f. Standoff Distance. The term "standoff distance" signifies the distance between the target and base of the hollow cavity. Since the standoff distance required for maximum penetration varies with the metal used as a liner, an optimum standoff distance can be established above and below which less penetration effect is obtained. As the jet is the penetrating agent, the function of the standoff distance is to provide time in which the jet can become extended to produce optimum penetration. Standoff distances of 5 and 9 inches were used in these tests. Small diameter wooden legs, taped to the charge containers, provided the 5- and 9-inch standoff distances (Fig. 13).



G9773

Fig. 13. Shaped charges with standoff legs attached.

g. Initiation. Initiation of the shaped charges was achieved by a special electric blasting cap placed in a booster pellet at the top center of the charge. To insure high-order detonation of the explosive, 15-gram PETN boosters were imbedded 3/4 inch into the top center of the charges (Fig. 14).

K1071

Fig. 14. Paste explosive shaped charge primed with J-2 special electric blasting cap inserted in booster pellet.

6. Shaped Charge Target. The target consisted of an 18-inch-high stack of steel plates 36 inches square (Fig. 15). The top layer of the stack was a 3-inch-thick armor plate, the next three layers were 1-inch-thick armor plates, and the remaining 12 layers were 1-inch-thick mild steel plates. The charges were placed on top of the stack for firing so that the penetrating jet was directed down through the target (Fig. 16).

7. Measure of Yield of the Charges. The holes produced by the charges were measured in two ways to provide two approaches for the analysis. The depth of the holes was used as the one measure of yield and the volume as the other.

8. Preliminary Test Shots. Ten charges were detonated to evaluate the validity of the test procedure and to test the equipment. Results of these test shots are shown in Table II.

G9770

Fig. 15. Stack of steel plates used for shaped charge target.

G9772

Fig. 16. Shaped charge placed for fir'n^ into target of steel plates.

Table II. Shaped Charge Test Data (Preliminary Test)

Charge Parameters						Results		
Charge	Explosive Type	Cone Type[(a)]	Explosive Weight (g)	Loaded Ht Above Vertex (in.)	Standoff (in.)	Penetration Depth (in.)	Penetration Volume (in.)	Avg[(b)] Surface Diameter (in.)
1	C-4	M	1,400	2-1/2	5	11.88	8.00	1.77
2	C-4	M	1,404	2-1/2	9	5.11	1.03	0.78
3	C-4	HF	1,425	2-1/2	9	14.91	6.13	1.40
4	C-4	HF	1,437	2-1/2	9	14.72	5.82	1.56
5	C-4	HF	1,395	2-1/2	9	13.97	6.38	1.46
						Avg 14.50	Avg 6.11	
6	C-4	HF	1,426	2-1/2	5	11.49	7.17	1.56
7	C-4	HF	1,380	2-1/2	5	11.86	7.77	1.72
						Avg 11.67	Avg 7.47	
8	C-4	HF	1,169	1-3/4	5	10.15	5.95	1.56
9	C-4	HF	1,193	1-3/4	5	11.88	7.17	1.43
						Avg 11.01	Avg 6.56	
10	C-4	HF	1,157	1-3/4	9	14.22	5.82	1.46

(a) The letters "M" and "HF" signify machined and hand-formed cones, respectively. Both types were 1/8-inch-thick copper, 3-1/2-inch-base-diameter, 60-degree-angle, truncated cones.

(b) The surface diameter of the hole is the average diameter occurring on the top target plate.

9. Test Procedure. The tests performed were designed as a full factorial experiment. In the first test series there were four factors, each at two levels. The factors with their two levels were: Type of cone (hand-formed and machined), type of explosive (Composition C-4 and paste), height of explosive above cone vertex (1-3/4 and 2-1/2 inches), and standoff distance from base of charge to target (5 and 9 inches). Since there were four factors, each at two levels, the total possible factor combinations were 16. Each factor combination was fired three times, making a total of 48 observations (test shots). The complete factorial design setup of one replicate is shown in Fig. 17.

In order to have a complete confounding of Factors A, B, C, and D in two blocks, each of the three replicates was subdivided into two blocks as follows:

Block 1 Shot	Block 1	Block 2 Shot	Block 2
1st	$A_2B_1C_1D_1$	1st	$A_1B_1C_1D_1$
2nd	$A_1B_2C_1D_1$	2nd	$A_2B_2C_1D_1$
3rd	$A_1B_1C_2D_1$	3rd	$A_2B_1C_2D_1$
4th	$A_1B_1C_1D_2$	4th	$A_1B_2C_2D_1$
5th	$A_2B_2C_2D_1$	5th	$A_2B_1C_1D_2$
6th	$A_2B_2C_1D_2$	6th	$A_1B_2C_1D_2$
7th	$A_2B_1C_2D_2$	7th	$A_1B_1C_2D_2$
8th	$A_1B_2C_2D_2$	8th	$A_2B_2C_2D_2$

The purpose of the second test series was to determine if the exudation of the oils from the paste explosive significantly affected the yield of the charges. Because only paste explosive was involved, the second test was a complete factorial experiment with only three factors, each at two levels. The three factors and their two levels were: Type of cone, hand-formed and machined; height of explosive above cone vertex, 1-3/4 and 2-1/2 inches; and standoff distance of base of charge to target, 5 and 9 inches. The three factors, each at two levels, yielded a total of eight factor combinations. Each factor combination was replicated two times so that the total observations were 16. The complete factorial design setup of one replicate is shown in Fig. 18.

	C_1D_1	C_1D_2	C_2D_1	C_2D_2
A_1B_1	Y11	Y12	Y13	Y14
A_2B_1	Y21	Y22	Y23	Y24
A_1B_2	Y31	Y32	Y33	Y34
A_2B_2	Y41	Y42	Y43	Y44

FACTORS:

A = Loaded height of explosive above vertex of cone.

A_1 = 1-3/4-inch height of explosive above vertex of cone.

A_2 = 2-1/2-inch height of explosive above vertex of cone.

B = Type of cone.

B_1 = Machined cone, 1/8-inch-thick copper, 3-1/2-inch-base-diameter, 60-degree-angle.

B_2 = Hand-formed cone, 1/8-inch-thick copper, 3-1/2-inch-base-diameter, 60-degree-angle.

C = Standoff distance from base of charge to target.

C_1 = 5-inch standoff distance.

C_2 = 9-inch standoff distance.

D = Type of explosive.

D_1 = Composition C-4 explosive.

D_2 = Paste explosive.

Y11 represents the yield obtained by using the combination explosive height above cone vertex A_1 and cone type B_1 and standoff distance C_1 and type of explosive D_1.

Fig. 17. Factorial design setup, Test Series 1.

	C_1	C_2
A_1B_1	Y11	Y12
A_2B_1	Y21	Y22
A_1B_2	Y31	Y32
A_2B_2	Y41	Y42

Factors "A" through "C" are the same as in the factorial design for Test Series 1.

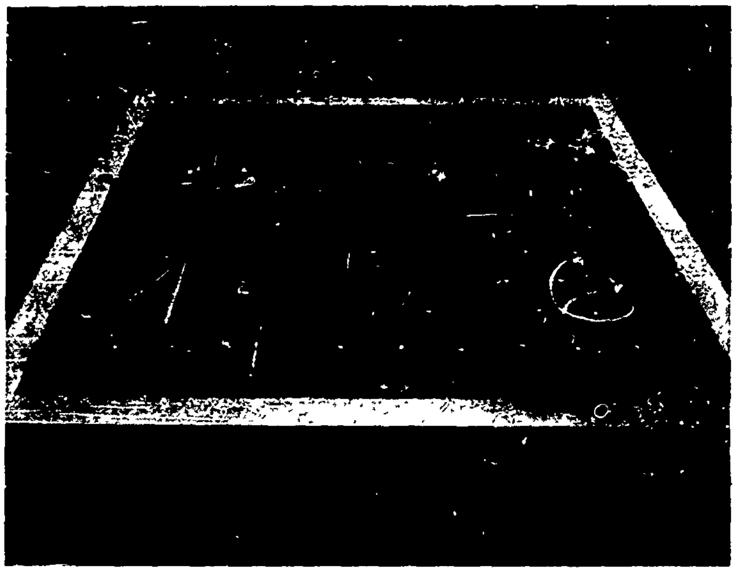
Fig. 18. Factorial design setup, Test Series 2.

In Test Series 2, to provide for the complete confounding of Factors A, B, and C in two blocks, each of the two replicates was subdivided into two blocks as follows:

Block 1 Shot		Block 2 Shot	
1st	$A_2B_1C_2$	1st	$A_2B_2C_2$
2nd	$A_2B_2C_1$	2nd	$A_1B_2C_1$
3rd	$A_1B_2C_2$	3rd	$A_1B_1C_2$
4th	$A_1B_1C_1$	4th	$A_2B_1C_1$

The surface area (36 by 36 inches) of the target stack of steel plates was subdivided into six rectangular areas 12 by 18 inches (Fig. 19). These six areas were the target surfaces for the eight charges of each experimental block design of Test Series 1. The four charges of each experimental block design in Test Series 2 were fired on target surface areas 1, 2, 4, and 5.

10. Test Methods. The first series of tests consisted of firing 48 shaped charges into a stack of steel plates and determining the depths and volumes of the resulting holes.



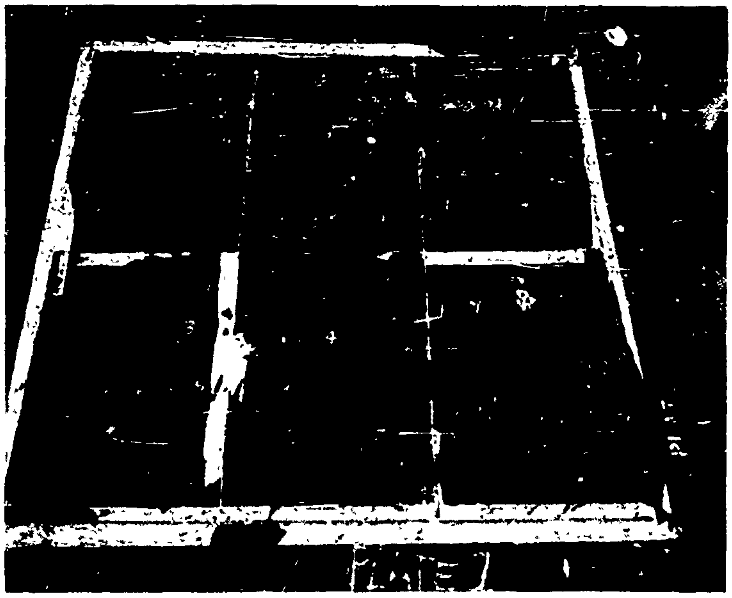
G9769

Fig. 19. Target surface subdivided into areas for shaped charge firings. (Small numbers indicate firing point for charges in each experimental block.)

Before the charges were fired, six areas 12 inches wide by 18 inches long were marked on the top target plate. These six areas were further subdivided into 3- by 3-inch squares to pinpoint the locations for the eight charges that were fired on each block (Fig. 19). By firing the charges at 3-inch intervals, no charge was fired closer than 3 inches to the plate edge, and sufficient area was available for firing additional charges, if required, to replace any "bad" shots. Also, since it was conceivable that the quality of the steel in one area might be superior to that in another, the random firing of charges in blocks would tend to minimize bias due to this factor. Figure 20 shows the locations at which all charges were actually fired.

The firing order and the exact firing location on the target for all charges were determined by random selection. This method was used to provide equal opportunity for the selection of any charge for firing at any time and at any location on the target plate. The series of 48 charges was fired during a period of 3 days.

The firing of the shaped charges on the target was closely controlled. After the correct standoff was provided by attaching three wooden legs, the charge was carefully aligned over the target area to be penetrated. Great care was taken to insure the common axis of the charge and cavity was as nearly perpendicular to the plane of the target surface as possible. Of equal importance was the proper priming of the charge. A special electric blasting cap was placed and taped 3/4 inch into the charge booster which was centered in the explosive column. Every effort was made to maintain the vertical alignment of the cap and booster, thus insuring uniform propagation of the shock wave.

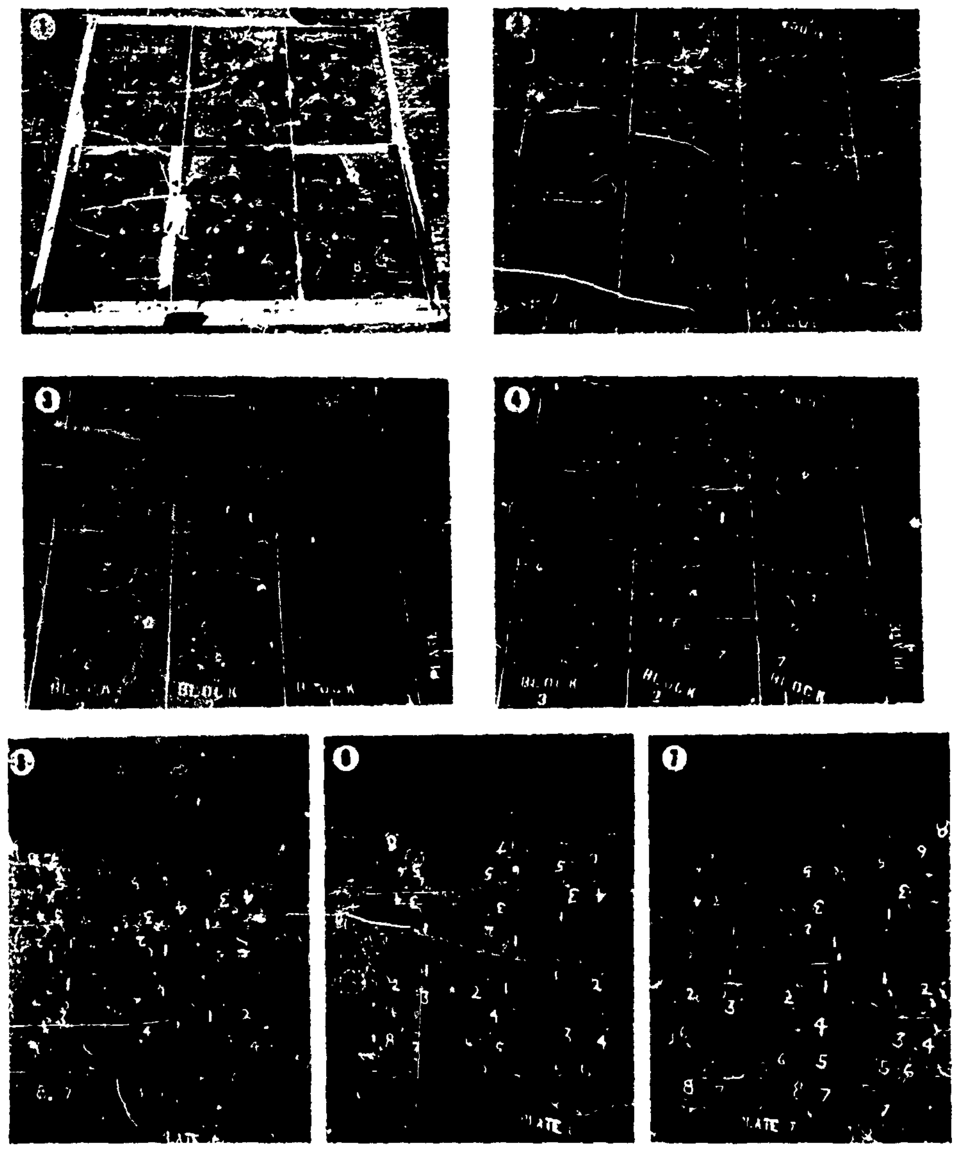


H1065

Fig. 20. Top target plate showing pattern of shaped charge firings.

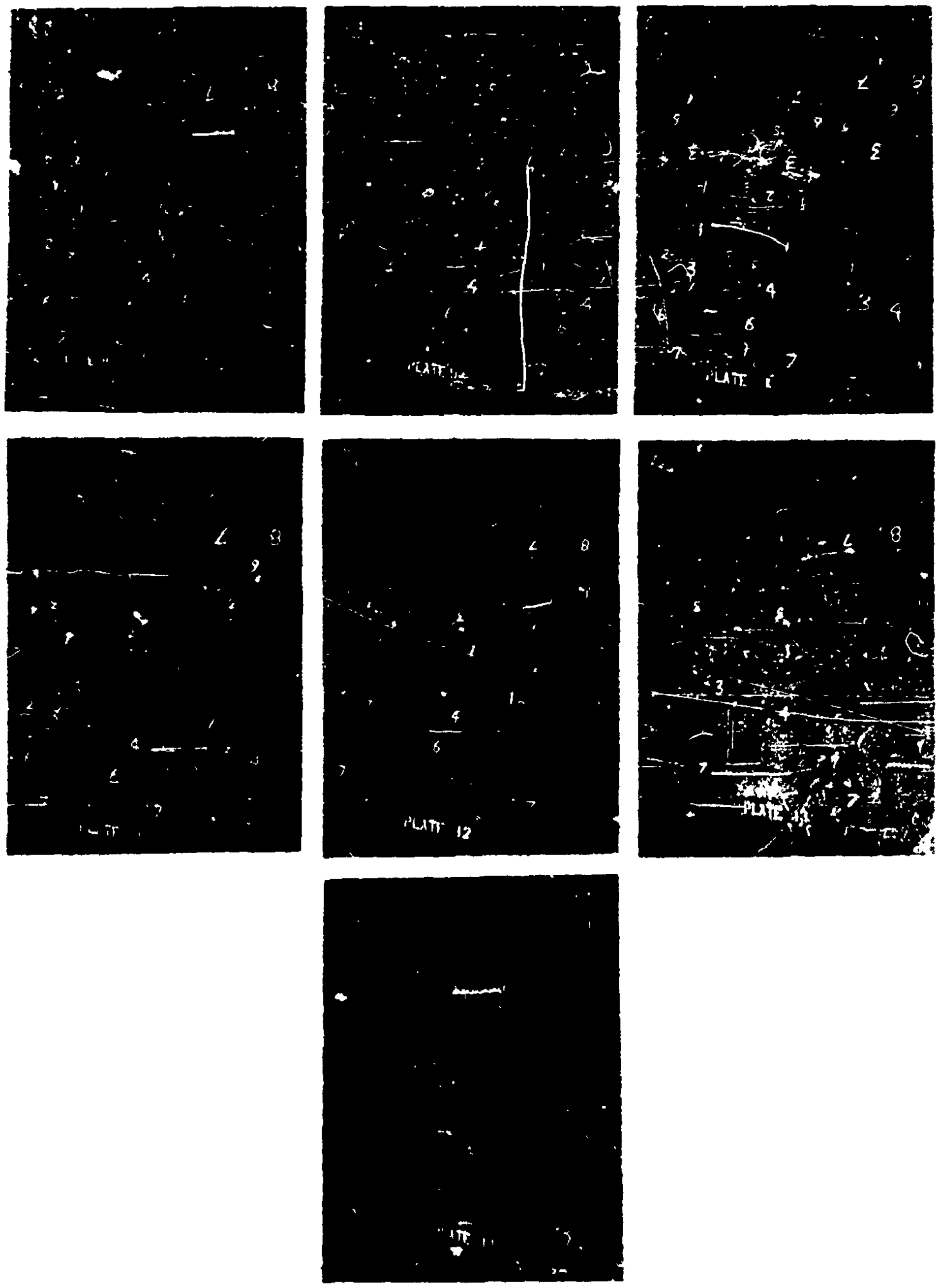
Each shot result was carefully examined before the succeeding shot was fired, and the target plates were examined for both shifting and warping. After all charges had been fired, the plates were separated, the holes were marked for identification, and the depth of the hole, its average diameter on each plate, and its volume were measured (Figs. 21a and 21b).

The average diameter of the holes in each plate was determined by averaging caliper measurements taken at 1/2 inch from the top in each hole in each plate. These hole diameters were the basis for calculating the volume of each hole.



H2029

Fig. 21a. Target plates 1 to 7 separated for measurement of yield.

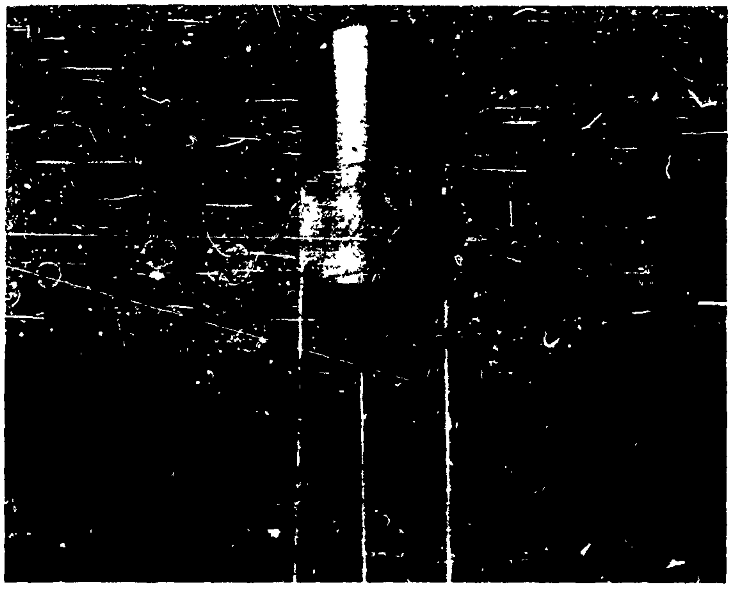


H2030

Fig. 21b. Target plates 8 to 14 separated for measurement of yield.

The depths of penetration were obtained by totaling the thicknesses of the plates perforated and adding to this total the depth of penetration into the last plate damaged by the shot. Calipers and a micrometer were used to make the measurements.

The 48 charges used in the test were in storage for 10 days before the test. During this 10-day period, the C-4 charges were apparently unaffected, but an average of 1/2 inch of oil had risen to the top of the paste charges, and some oil had sunk to the bottom and was partly retained on the masking tape seals. Having been soaked by the oil, the masking tape was slightly loosened, thus permitting the liners and explosive columns to slide 1/4 to 9/16 inch beyond the bottom of the charge containers. To determine if the exudation of oil and slippage of explosive column had significantly affected the yield of the paste charges, a second series of 16 paste charges was loaded at the firing site and immediately detonated on the target. These charges were fired during a 2-day period, and the loading, priming, and firing procedures were the same as those used in the first test series. Since the charges were loaded and fired immediately, oil did not exude from the explosive, but the explosive columns did slip an average of 1/8 inch beyond the charge containers. This slippage of the explosive column was caused by the combined weight of explosive filler and liner on the masking tape (Fig. 22).



G9771

Fig. 22. Slight protrusion of paste explosive filler beyond base of shaped charge container.

11. Test Results. A summary of all shaped charge firing data is shown in Tables III and IV. The tables list data on the design features of the charges as well as the dimensions of the resulting holes in the target. Charges are arranged in order of decreasing yield of penetration by groupings, according to similarity of charge parameters.

During the firing of the 74 shaped charges, the following observations were made:

a. The Composition C-4 charges produced more symmetrical holes than the paste charges. Inner surfaces of the C-4 charge penetrations were more uniform than the inner surfaces of the paste charge penetrations; moreover, the penetrations of the C-4 charges were more perpendicular to the target surface than the penetrations of the paste charges, indicating possible misalignment of the cones in the paste charges. In two paste charge shots, the jets veered and entered the target at a slight angle instead of perpendicular to the target face. The slugs from these charges followed the jet into the target but bounced out. One of these slugs is shown in the center of Fig. 6.

b. Because of the plasticity of paste explosive, shaped charges with paste explosive filler must be handled carefully to prevent the destruction of the jet-forming characteristics of the charges.

c. The priming of paste explosive shaped charges was more difficult than the priming of C-4 shaped charges. A PETN booster pellet, which was required for positive detonation, was dissolved by the explosive oil if allowed to remain in the paste charges overnight. Consequently, the booster pellet should be placed in paste charges immediately prior to firing. Care should be taken to avoid forming voids in the paste explosive when the booster pellet is inserted. Because of the insensitivity of paste explosive, such voids can cause misfires. Great care must also be taken when the blasting cap is placed in the booster to prevent the cap from penetrating through the booster hole and into the paste explosive. If the cap is pushed in too deeply, the base charge of the cap is not in contact with the booster charge, and a misfire may occur. A single blasting cap will not reliably detonate paste explosive. This problem may be solved by placing tape over the end of the booster which is inside the explosive column so that the cap will not be forced through the booster.

d. The slugs from the paste charges fired at 9-inch standoffs were invariably embedded in the top target plate, and the plate surface was spalled and splattered. These conditions were indicative of excessive standoff allowing breakup of the jet with resulting decrease in penetration and hole diameter.

Table III. Shaped Charge Test Data, Test Series 1

Charge Parameters						Results			
Charge Number	Explosive Type	Cone Type[a]	Explosive Weight (g)	Loaded Ht Above Vertex (in.)	Standoff (in.)	Penetration Depth (in.)	Penetration Volume (cu in.)	Avg[b] Surface Diameter (in.)	Order of Importance of Yield
17	C-4	M	1,221	1-3/4	9	14.79	5.59	1.00	
21	C-4	M	1,239	1-3/4	9	13.88	5.85	1.13	1
11	C-4	M	1,221	1-3/4	9	15.03	5.11	0.94	
						Avg 14.56	Avg 5.51		
18	C-4	M	1,422	2-1/2	9	13.92	6.71	1.18	
2	C-4	M	1,414	2-1/2	9	15.23	7.39	1.25	2
4	C-4	M	1,370	2-1/2	9	13.73	5.74	1.16	
						Avg 14.29	Avg 6.61		
7	C-4	HF	1,152	1-3/4	9	12.95	5.33	1.09	
22	C-4	HF	1,172	1-3/4	9	13.88	5.20	1.03	3
19	C-4	HF	1,185	1-3/4	9	14.79	5.73	1.03	
						Avg 13.87	Avg 5.42		
12	C-4	HF	1,332	2-1/2	9	12.70	5.30	0.95	
15	C-4	HF	1,327	2-1/2	9	12.87	5.94	1.16	4
5	C-4	HF	1,346	2-1/2	9	13.73	6.05	1.00	
						Avg 13.10	Avg 5.76		
1	C-4	M	1,420	2-1/2	5	12.14	7.20	1.31	
6	C-4	M	1,355	2-1/2	5	11.67	5.88	1.13	5
8	C-4	M	1,378	2-1/2	5	11.67	6.61	1.19	
						Avg 11.82	Avg 6.56		
3	C-4	M	1,215	1-3/4	5	11.67	6.66	1.24	
20	C-4	M	1,223	1-3/4	5	11.95	6.33	1.19	6
23	C-4	M	1,218	1-3/4	5	11.67	6.55	1.13	
						Avg 11.76	Avg 6.51		
32	Paste	M	1,388	2-1/2	[illegible]	9.86	6.33	1.45	
33	Paste	M	1,388	2-1/2		10.60	4.03	0.94	7
38	Paste	M	1,388	2-1/2		11.67	4.52	0.98	
						Avg 10.77	Avg 4.96		
9	C-4	HF	1,151	1-3/4	5	10.86	6.23	1.30	
14	C-4	HF	1,130	1-3/4	5	10.89	4.00	0.88	8
16	C-4	HF	1,175	1-3/4	5	9.64	2.83	0.81	
						Avg 10.46	Avg 4.35		
29	Paste	M	1,223	1-3/4	5	11.67	6.10	1.09	
27	Paste	M	1,223	1-3/4	5	8.70	3.47	0.97	9
46	Paste	M	1.223	1-3/4	5	10.61	3.83	0.94	
						Avg 10.32	Avg 4.46		
34	Paste	HF	1,410	2-1/2	5	9.72	5.59	1.28	
45	Paste	HF	1,410	2-1/2	5	8.82	4.36	1.12	10
43	Paste	HF	1,410	2-1/2	5	10.98	5.26	1.09	
						Avg 9.54	Avg 5.07		
10	C-4	HF	1,343	2-1/2	5	11.26	5.93	1.16	
13	C-4	HF	1,325	2-1/2	5	4.36	2.97	1.06	11
24	C-4	HF	1,396	2-1/2	5	11.92	6.96	1.16	
						Avg 9.18	Avg 5.28		
35	Paste	HF	1,410	2-1/2	9	8.11	3.21	0.92	
47	Paste	HF	1,410	2-1/2	9	7.80	4.50	1.19	12
39	Paste	HF	1,410	2-1/2	9	9.76	2.88	0.75	
						Avg 8.55	Avg 3.53		
37	Paste	M	1,223	1-3/4	9	8.94	4.75	1.26	
36	Paste	M	1,223	1-3/4	9	5.96	3.17	0.98	13
25	Paste	M	1,223	1-3/4	9	7.80	1.84	0.65	
						Avg 7.56	Avg 3.25		
44	Paste	M	1,388	2-1/2	9	7.80	3.77	1.07	
30	Paste	M	1,388	2-1/2	9	6.86	3.50	1.13	14
31	Paste	M	1,388	2-1/2	9	6.20	2.66	0.88	
						Avg 6.95	Avg 3.31		
48	Paste	HF	1,175	1-3/4	5	3.71	1.92	0.78	
41	Paste	HF	1,175	1-3/4	5	11.67	6.69	1.22	15
26	Paste	HF	1,175	1-3/4	5	5.18	1.68	0.72	
						Avg 6.85	Avg 3.43		
40	Paste	HF	1,175	1-3/4	9	6.30	4.60	1.31	
28	Paste	HF	1,175	1-3/4	9	3.18	0.71	0.53	16
42	Paste	HF	1,175	1-3/4	9	3.12	2.98	1.13	
						Avg 4.20	Avg 2.76		

(a) The letters "M" and "HF" signify machined and hand-formed cones, respectively. Both types were 1/8-inch-thick copper, 3-1/2-inch-base-diameter, 60-degree-angle, truncated cones.

(b) The surface diameter of the hole is the average diameter occurring on the top target plate.

Table IV. Shaped Charge Test Data, Test Series 2

Charge Parameters						Results				
Charge Number	Explosive Type	Cone Type(a)	Explosive Weight (g)	Loaded Ht Above Vertex (in.)	Standoff (in.)		Penetration Depth (in.)		Penetration Volume (cu in.)	Avg(b) Surface Diameter (in.)	Order of Importance of Yield
15	Paste	M	1,223	1-3/4	9		10.61		4.17	0.94	1
16	Paste	M	1,223	1-3/4	9		10.80		4.62	1.06	
						Avg	10.70	Avg	4.39		
11	Paste	HF	1,175	1-3/4	9		11.67		5.66	1.12	2
12	Paste	HF	1,175	1-3/4	9		8.83		4.25	1.09	
						Avg	10.25	Avg	4.95		
1	Paste	M	1,388	2-1/2	5		10.61		3.64	0.93	3
3	Paste	M	1,388	2-1/2	5		9.64		3.04	0.75	
						Avg	10.12	Avg	3.34		
5	Paste	HF	1,410	2-1/2	9		8.70		5.20	1.30	4
7	Paste	HF	1,410	2-1/2	9		10.61		4.58	1.00	
						Avg	9.65	Avg	4.89		
8	Paste	HF	1,410	2-1/2	5		8.70		2.79	0.78	5
6	Paste	HF	1,410	2-1/2	5		9.64		3.18	0.84	
						Avg	9.17	Avg	2.98		
9	Paste	HF	1,175	1-3/4	5		6.86		3.60	1.00	6
10	Paste	HF	1,175	1-3/4	5		10.99		5.06	1.09	
						Avg	8.92	Avg	4.33		
2	Paste	M	1,388	2-1/2	9		9.64		4.27	1.06	7
4	Paste	M	1,388	2-1/2	9		7.08		2.51	0.78	
						Avg	8.36	Avg	3.39		
13	Paste	M	1,223	1-3/4	5		9.86		4.14	1.09	8
14	Paste	M	1,223	1-3/4	5		4.24		1.83	0.81	
						Avg	7.05	Avg	2.98		

(a) The letters "M" and "HF" signify machined and hand-formed cones, respectively. Both types were 1/8-inch-thick copper, 3-1/2-inch-base-diameter, 60-degree-angle, truncated cones.

(b) The surface diameter of the hole is the average diameter occurring on the top target plate.

III. DISCUSSION

12. Examination of Test Methods. Many variables affect the performance of a shaped charge. Of these, some of the more important are: Type of explosive, height of the explosive above cone vertex, confinement of the charge, initiation of the charge, type of liner, shape of the liner, standoff distance of the base of the charge from the target, and symmetry of the charge.

a. Type of Explosive. It is evident that an explosive with greater strength than another will be more effective in producing shaped charge jets. The higher the rate of detonation of the explosive, the greater the penetration and the damaging properties. Tests were conducted with two kinds of explosive, Composition C-4 and paste. In previous tests, the detonating velocity of Composition C-4 with a density of 1.57 grams per cubic centimeter had been shown to be about 26,000 feet per second,[6] while preliminary tests with paste explosive revealed its detonating velocity to be about 24,000 feet per second with a density of 1.52 grams per cubic centimeter.[7] The difference in the detonating velocity of the two explosives accounts to some extent for the deeper penetrations achieved with the charges loaded with C-4 explosive. Although an attempt was made to hand load the two types of explosive to about the same density, it was virtually impossible to obtain uniform density loadings among charges because of the extreme difficulty involved in controlling the many sources of error inherent in the hand-loading method. Also, it was found that with hand loading, the density of the paste charges could not be increased beyond 1.52 grams per cubic centimeter because of the oiliness and adhesiveness of paste explosive. The paste explosive was sticky and oily and many oil pockets existed in the explosive mass. An effort was made to eliminate these oil pockets by working the explosive with a metal spoon during the loading; however, by X-raying the charges, the paste charges were disclosed to contain more low-density areas than the C-4 charge, thus resulting in lower penetrations with the paste charges.

Another source of error with paste explosive is its characteristic exudation of oils. Test Series 1 charges were stored 10 days before detonation. In that time, 1/2 inch of oil rose to the top of the explosive. Some sank to the bottom. Part of this was caught on the masking tape which held the conical liners in the

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6. John Cogan, Comparative Testing of United Kingdom Explosive PE-4 and Composition C-4, Report 1650-TR, USAERDL, Fort Belvoir, Virginia, 23 September 1960.

7. Howard J. Vandersluis, Preliminary Evaluation of Paste Explosive, Report 1697-TR, USAERDL, Fort Belvoir, Virginia, 31 October 1961.

charges. Test Series 2 charges were loaded and fired immediately, so no oil was lost by exudation. Out of eight pairs of tests, series 2 charges were superior in 5; a series 1 charge was superior in 1; and the difference was insignificant in 2 (Fig. 23).

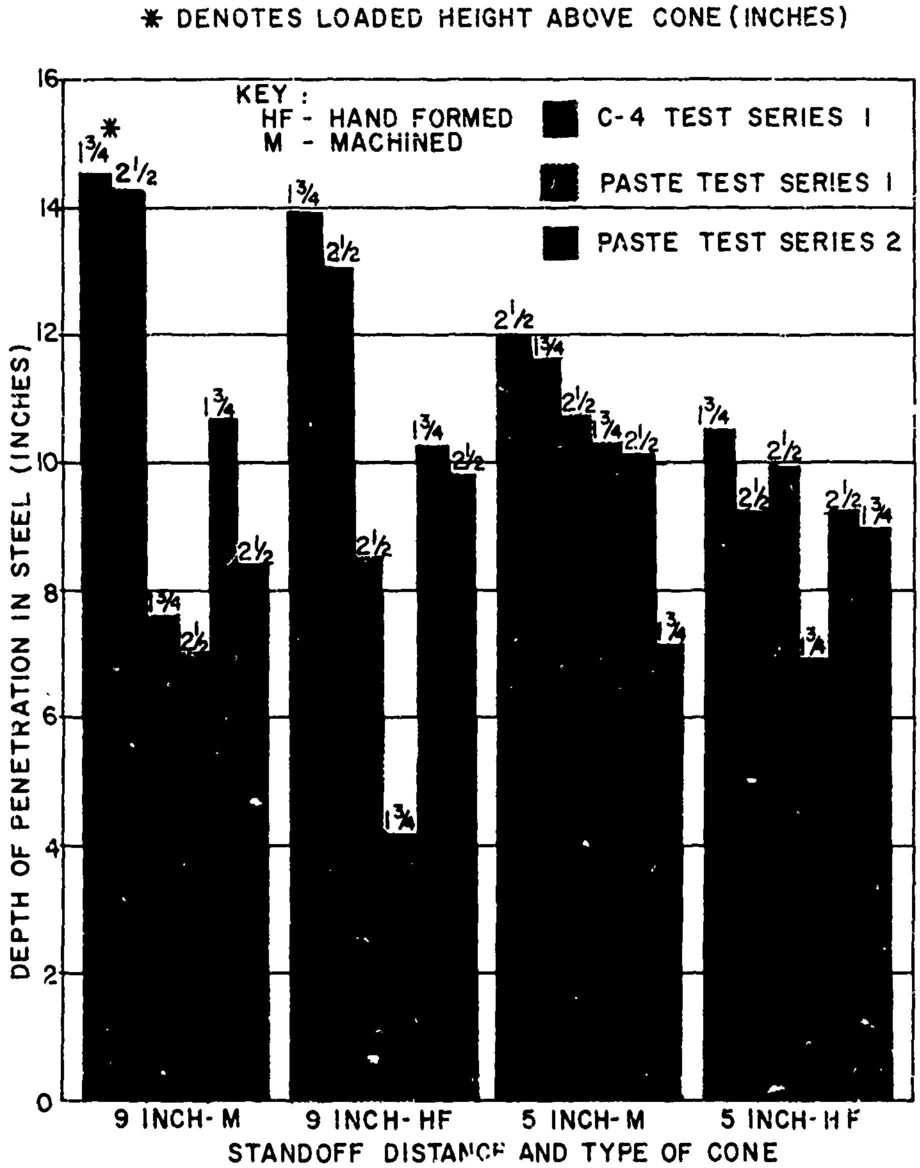

Fig. 23. Significance of explosive type.

This source of error due to exudation of oils can be eliminated by loading the paste charges immediately before firing. This is as it should be for combat demolitions, because transportation of prepared shaped charges having paste explosive filler will disrupt the charge symmetry and result in greatly reduced jet-forming characteristics.

Like the exudation of oil, the slippage of the paste explosive column beyond the bottom of the charge container provided a source of error with the paste charges. As the explosive column became extended beyond the container bottom, the cavity liner was moved slightly beyond the bottom of the container, and some misalignment of the cavity axis with the charge axis no doubt occurred. Likewise, movement of the explosive column and cavity liner possibly reduced contact between the explosive filler and the cavity liner. The misalignment of the cavity liner together with the decrease in contact between the explosive filler and the cavity liner probably accounts, to a degree, for the veering of the penetrating jets as well as the formation of asymmetrical penetrations by the paste charges. Surely, this source of error adversely affected the yield of the paste charges. To minimize error due to slippage of the explosive column and cavity liner, all charges were inspected and, where necessary, realigned and retaped prior to firing. Movement of the explosive column and cavity liner can be prevented by spot welding the liner to the charge container; however, this solution might also adversely affect the yield of the charge and would require testing to determine its effect.

As a result of loading the C-4 explosive in small, hand-tamped increments, low-density areas no doubt existed at the junctures of the various loading increments. These low-density areas probably resulted in some nonuniformity in propagation of the shock wave through the explosive column. Nonuniformity of propagation undoubtedly resulted in failure of the shock wave to simultaneously impinge on the liner, thus impairing the formation of the penetrating jet. The difference in the densities among the charges loaded with both Composition C-4 and paste explosive affected their detonating velocities with corresponding effect on their jet penetrating properties. With hand-loaded shaped charges, lower density of the explosive charge with corresponding decrease in detonating velocity and penetrating results must be accepted because there is no known method of obtaining controlled loading densities.

b. Height of the Explosive Above the Cone Vertex. For a shaped charge liner of given diameter, there is an optimum height of the explosive column above the liner vertex. The optimum height of the explosive column depends on such factors as confinement of the charge, liner characteristics, etc. It has been shown that for a given design of shaped charge there exists an optimum ratio of charge diameter to charge height above which the increase in effectiveness of the charge decreases rapidly.[8] Previous tests[9] concluded that a charge height of 2 inches above the liner vertex produced optimum results with hand-formed, conical, copper liners having 3-1/2-inch base diameters; therefore, it was decided to bracket the 2-inch loaded height by using 1-3/4- and 2-1/2-inch charge heights and thereby test other charge heights with the machined cones and paste explosive. When the C-4 charges were loaded to controlled heights of 1-3/4 and 2-1/2 inches above the cone vertex, the charge weights varied among the charges because of the difference in densities obtained during loading as well as the slight difference in configuration between hand-formed and machined liners. This difference in explosive weight undoubtedly influenced the penetrations and volumes obtained in the target, but this increase or decrease in yield among the C-4 charges due to variation in the charge weight was so slight as to be insignificant.

Because of the lower density of the paste explosive (paste 1.52 grams per cubic centimeter, C-4 1.57 grams per cubic centimeter), the loading of paste charges to controlled heights of 1-3/4 and 2-1/2 inches above the cone vertex would have resulted in charge weights which would have been less than weights for like C-4 charges. Holding the weights of the paste charges constant with the weights of similar C-4 charges was thought to provide more accurate comparison of results than would controlling the charge heights; hence, the paste charges were loaded by weight rather than by charge height above cone vertex. As a result, the paste charges designated as 1-3/4-inch charge height actually were loaded to heights varying from 2-1/4 to 2-5/16 inches, while the paste charges designated as 2-1/2-inch charge heights were loaded to heights varying from 2-13/16 to 3 inches. This difference in charge height between the C-4 and paste charges affected the yield of the charges, but the effect was not as significant as a difference in charge weight would have been. The error caused by this variation in charge height was insignificant when compared with other sources of error, such as low density of explosive, exudation of oil, lack of homogeneity, and difficulty in maintaining good contact between explosive and liner--errors that are inherent in shaped charges loaded with paste explosive.

c. Confinement of the Charge. Confinement of the explosive charge restrains the gas pressure from escaping sideways and helps to maintain pressure on the cavity liner during its collapse. Thus, charges are normally confined in steel casings; and, for

8. R. S. Lewis and G. B. Clark, Application of Shaped Charges to Mining Operations - Tests on Steel and Rock, Bulletin, University of Utah, July 1946.

9. Vandersluis, Improvised Shaped Charges.

conical liners, an increase in confinement tends to increase the hole diameter. As maintenance of pressure is only important during collapse of the liner, a limiting value of the degree of the confinement which will improve the results is soon reached. The charges used in this test program were encased in 21-gage sheet steel casings which apparently provided adequate confinement for the shaped charge design. Hence, there was little experimental error due to insufficient confinement of the charge.

d. Priming and Initiation. The formation of penetrating jets by shaped charges requires that the charges be initiated from the end opposite the cavity. Initiation by a detonator placed at the rear of the charge results in the shock wave impinging directly on the liner. With desensitized high explosive such as paste explosive, the use of a booster is necessary to insure detonation.

Close control of the priming and initiating of improvised shaped charges is difficult. Inserting the PETN booster exactly 3/4 inch into the explosive filler, centering it accurately, and lining it up completely perpendicular to the charge top and parallel to the charge axis was difficult and infeasible. Moreover, with the paste charges, maintaining this alignment would have been virtually impossible, once achieved. Like the placement of the booster, maintaining close tolerance while inserting the blasting cap exactly 3/4 inch into the booster and securing the cap so that it was perpendicular to the charge surface was not possible. Thus, both the boosters and blasting caps were placed and aligned by eye, and, after alignment, the blasting caps were secured in a vertical position by masking tape. Although care was exercised in priming the charges, the shot yields were no doubt affected to some extent by inexact priming. Incorrect alignment of the booster or blasting cap results in nonuniformity in propagation of the shock wave, thus causing disruption of the normal progression of the jet formation. With improvised shaped charges, however, the effect of inexact priming is not as critical as with precision manufactured charges because of the lack of other close tolerances in the improvised charge.

Variation in the power of blasting caps may have provided another slight source of error. Although Hercules special electric blasting caps of the same lot were used throughout the test, some of the caps could have been stronger or weaker than others, with resulting variation in the rate of detonation of the charges. It is thought that the strength of caps is affected by age and storage conditions. In all but one shot, however, the charges were initiated to complete detonation. Where the charge failed to detonate, the cause was more likely due to penetration of the base charge of the cap beyond the booster and into the paste rather than due to a weak cap.

When the many sources of error affecting the yield of improvised shaped charges are considered, the error due to inexact priming and initiation would seem to be the least significant, provided normal care was exercised.

e. Type of Liner. The effect that the type of liner had on the shaped charge yield was considerable as had been expected. Although both types of cones were formed from 1/8-inch, annealed copper, the machined cones were manufactured to close tolerances by the spin process, while the improvised cones were shaped by hand-forming from sheet copper. Consequently, the hand-formed cones were of uneven quality and provided a greater source of error and variation in results than did the machined cones. This fact is verified by the yield results (Tables III and IV) wherein the more consistent and higher yields were obtained with the machined cones.

When a metal liner is present in the cavity of a shaped charge, the liner collapses during detonation resulting in a stream of high-velocity gases and metal particles capable of penetrating a considerable depth into steel, concrete, earth, and the like. Depth of penetration and volume of the hole are known to be functions of the thickness of the liner (among other parameters); an optimum thickness exists for maximum depth of penetration, while a somewhat different optimum thickness exists for maximum hole volume.[10] If the liner is of uneven wall thickness, nonuniform jet particles and jet wavers are formed. The influence of jet ductility and jet wavers, due to liner imperfections, have been shown to comprise two of the weakest factors in shaped charge design.[11] Wall thickness variation has more adverse effect than other imperfections, but the effect of any faults becomes greater the closer they are located to the base of the cone. This is because the proportion of the material in a cross section entering the high velocity jet increases from less than 20 percent at the apex to more than 50 percent at the base of the cone.[12]

Shaping of the improvised liners used in these tests consisted of hand-forming and welding operations followed by sanding to obtain maximum uniformity. Although great care was exercised by skilled workmen in fabricating the liners, the hand-forming process

10. George B. Clark and Walter H. Bruckner, Behavior of Metal Cavity Liners in Shaped Explosive Charges, A.I.M.E. Technical Publication Number 2158, May 1947.

11. Melvin A. Cook, The Science of High Explosives, Reinhold Publishing Company, New York, 1958.

12. Arthur D. Little, Inc., Collection and Arrangement of Shaped Charge Data, Third Interim and Final Report, Vol. 1, 31 December 1959.

led to cone liners of inconsistent quality. Error due to liner imperfection cannot be completely eliminated with improvised liners.

Because the machined cones were manufactured to close tolerances, error due to their imperfection was considered insignificant.

f. Shape of the Liner. Sixty-degree conical liners were used exclusively for both machined and hand-formed liners during these tests. Error due to this parameter was thought to be virtually uncontrollable by test personnel. The machined liners, no doubt, contributed little source of error, but minor deviations in the fabrication of the improvised liners affected their yields. As with other imperfections inherent in improvised shaped charges, this source of error must be accepted.

g. Standoff Distance. Optimum standoff distance must be determined experimentally for each type of shaped charge design. If the standoff distance is optimum, collapse of the liner and formation of the jet can be complete before the jet reaches the target. The results of this are maximum penetration of the target because the jet is the penetrating agent. After a certain standoff distance, however, the jet has a tendency to break up both axially and radially, and penetrating effect is decreased.

Since the primary objective of this test program was the evaluation of paste explosive as a filler for improvised shaped charges, only two levels of standoff distance, 5 and 9 inches, were tested. The testing of only two levels of the standoff variable thus produced yields that show which of the two standoffs gave best results and does not indicate the optimum standoff for the charge designs tested. Establishment and use of the optimum standoff distance for the charge designs might have resulted in greater yields; nevertheless, the yields obtained do provide a sound basis for the evaluation of the types of explosives and conical liners that were tested.

h. Symmetry of the Charge. The assembly and loading of improvised shaped charges requires great care if maximum and reproducible penetration effects are to be obtained. Misalignment of the cavity axis with the axis of the explosive charge causes decrease in the penetration yield of the jet. Uneven thickness of the liner, formation of nonuniform layer of explosive at the base of the cavity, and voids or low-density regions in the explosive charge all have adverse effects on the penetration value. These adverse effects are more pronounced for small than for large charges. Although the charges were all assembled and loaded by one man who exercised extreme care, there was no doubt some inexactness which adversely influenced the results. To minimize errors due to asymmetry of the charge, all charges were carefully inspected by two persons prior to being accepted for test firing. Every possible effort was made to detect and correct defects, such as cracks or voids in the explosive, nonuniform thickness of the liner, and nonconcentricity of the liner in the charge.

i. Errors Due to Variations in the Test Materials and Procedure. The result of each charge fired was no doubt affected by variations in each charge and the steel plates used as the target as well as the procedure of placing and firing the charge and measuring the yield. To minimize the errors, the charges were selected at random for loading and firing, and the steel target plates were cut from large plates. In measuring the yield of each shot, one man made all the measurements which were averaged from several readings of both the depth of penetration and diameter of the hole in each plate. In general, the variations were believed not great enough to have a detectable influence, but every precaution was taken to eliminate such variations.

13. Analysis of Test Results. To permit quantitative evaluation of results, the tests were conducted by using a full factorial design, and the results were analyzed by several statistical techniques. The various statistical analyses are described in detail in Appendix B. In the following paragraphs, the test analysis is discussed in terms of the parameters of the shaped charge designs that were tested.

a. Considerations of Explosive Properties. As was anticipated at the beginning of the tests, Composition C-4 explosive produced greater and more consistent yields than the paste explosive (Fig. 23). The analysis of variance, calculated with both the penetration depths and volumes from Test Series 1 (Table III), showed the type of explosive to be highly significant (Appendix B). Comparison of paste explosive to Composition C-4 as a shaped charge explosive is readily apparent from the averaged results presented in Fig. 23 and Table III. In Table III, the greatest penetration yields are listed first, grouped according to like charge parameters. The Composition C-4 charges gave greater yields in all but three of the charge groupings. This superiority of C-4 explosive over paste explosive may be explained by closely examining certain qualities of the two explosives.

(1) Rate of Detonation. In paragraph 12a, it was pointed out that the higher the rate of detonation of the explosive, the greater its penetrating and damaging properties. Composition C-4 explosive at a density of 1.57 grams per cubic centimeter has a detonating velocity of about 26,000 feet per second while paste explosive at a density of 1.52 grams per cubic centimeter has a detonating velocity of about 24,000 feet

per second. Hence, this 2,000-feet-per-second difference in detonating velocity was a significant factor in producing the greater yields with the C-4 explosive. Likewise, more uniform densities were obtained by hand-tamping the C-4 charges than was possible by working the paste explosive with a tamping stick to eliminate oil bubbles. The oil bubbles in the paste explosive adversely affected its detonating velocity and shock wave propagation with resulting reduction in penetrating effect. Since density of the explosive charge is known to affect the rate of detonation of the charge, the more uniform densities of the Composition C-4 charges account to some extent for their more consistent yields.

(2) Brisance of the Explosives. Brisance is the shattering power of an explosive, as distinguished from its total work capacity. As the shattering power of an explosive is dependent upon the suddenness with which the gaseous products of the explosions are liberated, the rate of detonation is at least a major factor in determining brisance. With military explosives, several methods (Sand Test, Plate Dent Test, Fragmentation Test) are used to determine their brisance. Table II, "Effects of Explosives," in Department of the Army TM 9-1910, shows Composition C-4 to be 115 percent as effective as TNT when measured by the plate dent test. Since Composition C-4, the principal ingredient of paste explosive, is composed of about 91 percent RDX as compared to about 76 percent RDX for paste explosive (Table I), it is evident that C-4 has a higher brisance than paste explosive. U. S. Army Engineer Research and Development Laboratories tests[13] have also shown that paste explosive is not as effective as C-4 for steel cutting, thus indicating a lesser shattering ability for paste explosive. The higher brisance of Composition C-4 assisted in producing greater yields with the C-4 shaped charges.

(3) Consistency of Explosive. Although the Composition C-4 charges were more difficult to load, the jet-forming characteristics were not noticeably affected by handling, transporting, and storage. Conversely, after storage, the oils of the paste explosive had risen to the top of the charge and some oil had leaked through the bottom masking tape seal. Also, paste explosive tended to slump and cause the explosive column to protrude beyond the base of the liner and charge casing. It was conceivable that some of the paste slumped beyond the conical liner and, upon detonation of the charge, disrupted the proper formation of the penetrating jet. Like the slump characteristics, the forming of oil bubbles in the paste column, especially adjacent to the liner, adversely influenced the yields

13. Vandersluis, Preliminary Evaluation of Paste Explosive.

of the paste charges. Moreover, while the Composition C-4 charges were not very susceptible to misalignment of the cavity liner during handling and transporting, the paste explosive charges were susceptible because of the plasticity of the paste filler, and some misalignment of the cavity liner no doubt occurred. Although slight, this misalignment of the cavity liner probably decreased the yields with the paste charges.

b. Effect of Explosive Height Above Cone Vertex. The statistical analysis of the test results showed that, for the shaped charge designs tested, the height of the explosive above the cone vertex was not significant. Close examination of the yields in Tables III and IV seems also to show this insignificance. It appears that for small shaped charges, such as those tested, this variable is not highly critical within the range of 1-3/4 to 2-1/2 inches. Because it is known that a given design of shaped charge has an optimum ratio of charge diameter to charge height, the variable is no doubt critical for larger and smaller charges. Testing of a wider range of charge heights above the cone vertex would probably have revealed the variable to be significant. Before the tests, it was believed that this variable was significant with small charges.

c. Effect of Explosive Weight. Although not a variable of the tests, due to the loading of the charges according to height above cone vertex, a variety of explosive weights were used. With the C-4 charges, the explosive weights varied from 1,130 to 1,422 grams, and the weights of the explosive in the paste charges varied similarly. In spite of the variance in explosive weights among charges, greater yields were obtained in many instances with charges loaded with lesser weights of explosive (Tables III and IV). Thus, although previously considered critical, as with height of the explosive above cone vertex, the weight of the explosive in the shaped charge does not appear to be a critical factor within a range of about 100 to 300 grams.

d. Effect of Cone Characteristics. Statistically, as thought at the beginning of the tests, the type of cone was shown to be highly significant. The analysis of variance (Appendix B) reveals the machined cone to be highly significant when compared to the hand-formed cone, but the test results (Tables III and IV) disclose that while type of cone is significant, the significance is not as great as was previously expected. With hand-formed cones and C-4 explosive, average penetrations of 12 to 14 inches were obtained that compare favorably with penetrations of the machined cones and C-4 explosive (Fig. 24). In addition, the average penetrations obtained with hand-formed cones and paste explosive closely approach those penetrations obtained with machined cones and paste explosive (Figs. 25 and 26). The insignificance of liner type with the paste explosive is probably caused by the lack of consistency in the paste explosive filler, previously discussed.

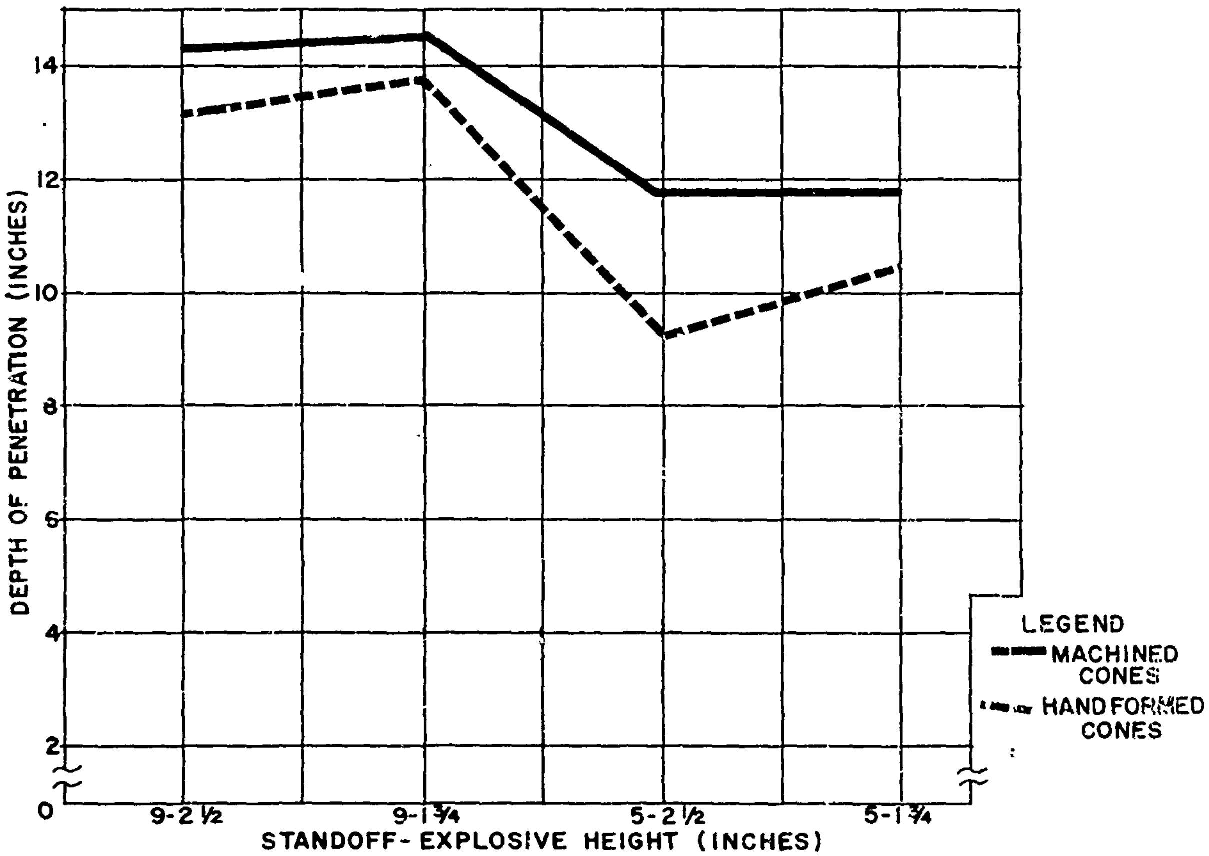

Fig. 24. Cone significance with C-4 explosive - Test Series 1.

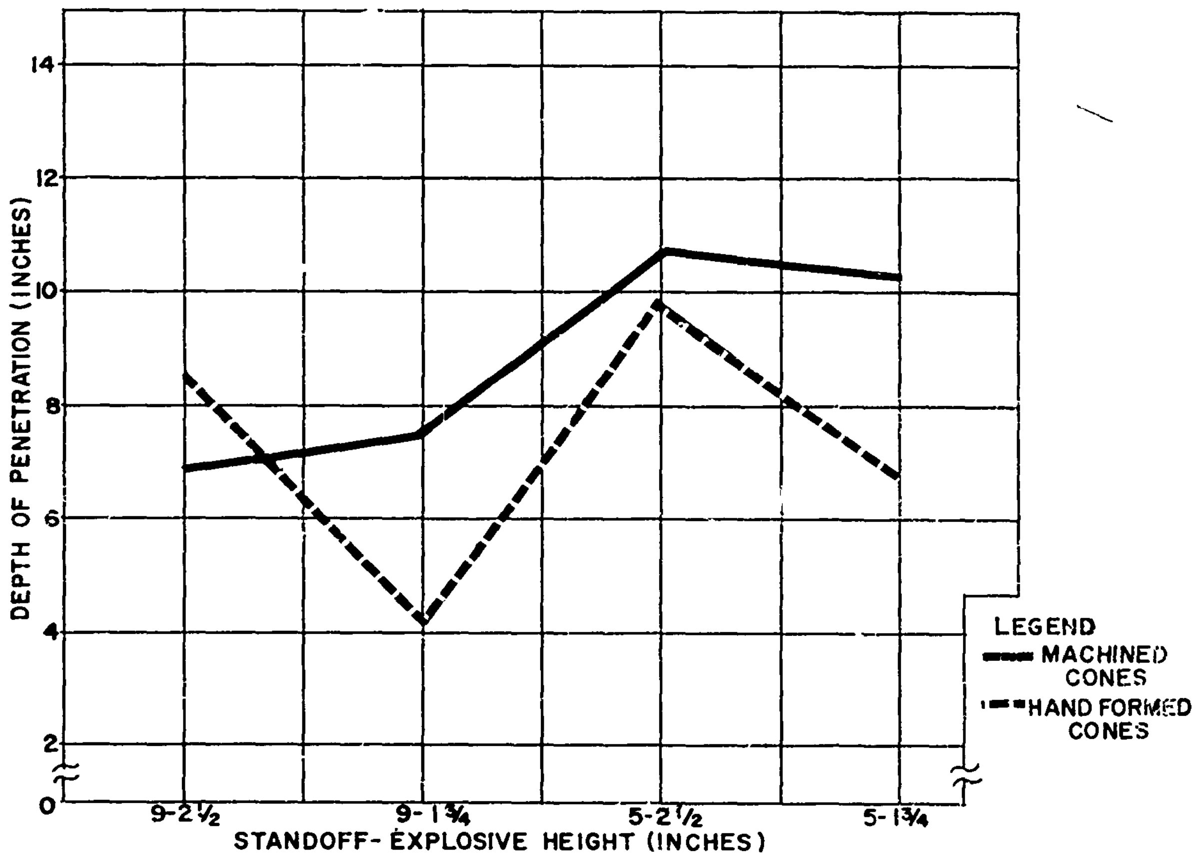

Fig. 25. Cone significance with paste explosive - Test Series 1.

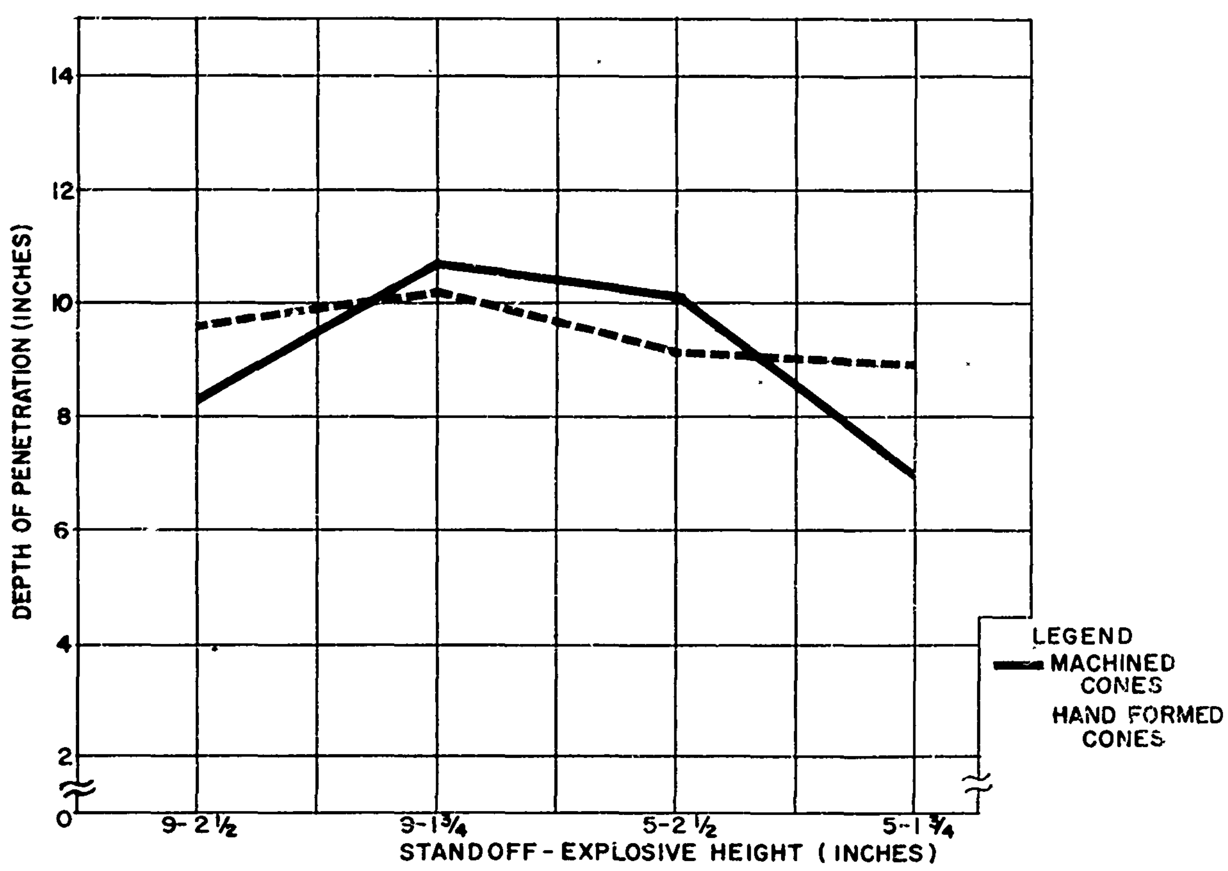

Fig. 26. Cone significance with paste explosive - Test Series 2.

The close tolerances in the machined cones considerably influenced the greater penetrations achieved with them. Likewise, the uneven quality of the hand-formed cones contributed a source of error that reduced their yield values. Liner tolerances have been shown to be more critical near optimum standoff than they are at low standoff.[14] At short standoff--5 to 15 inches--the effects of precision liner fabrication on penetration are slight With increasing standoff, beyond optimum, penetration depth decreases slowly for machined liners, more quickly for hand-formed. Apparently, liner characteristics are not as critical for shaped charges used for general demolitions tasks as for shaped charge ammunition.

e. Effect of Standoff Distance. In the analysis of variance calculated with Test Series 1 yields, there was no significance in standoff distance, but there was significant first order interaction with type of explosive and standoff distance. By examining the yields of the charge groupings in Fig. 23, the importance of standoff can be clearly understood. With Composition C-4 explosive, the 9-inch standoff distance gave the best averaged results in all charge groupings. Similarly, the 5-inch standoff distance gave the greater yields with the paste explosive. The lower density and detonating velocity of the paste charges as well as the effect of oil pockets on uniform propagation of the shock wave probably decreased the penetrating properties of the jet. These effects together with the other sources of error with paste explosive, previously discussed in paragraph 12a, probably disrupted the proper forming of the penetrating jet, causing the jet to break up sooner, thus reducing its effective length. This would account for the greater yields with paste charges at 5-inch standoff. Contrarily, the higher detonating velocity, greater density, and more uniform symmetry of the Composition C-4 charges produced longer and higher velocity jets requiring greater standoff distances for proper forming of the jet. As stated previously, the jet is the penetrating agent; and, as standoff distance is brought into existence and increased, there is more time for the jet to become extended before striking the target. The results of this are increase in depth of penetration and decrease in diameter of hole produced. Hence, this explains why in comparing depths and volumes as measurements of yield, with depths, the type of explosive interacts with distance whereas the same is not true with volumes used as a measurement of yield (Appendix B, page 55).

f. Comparison of Results with Paste Charges in Test Series 1 and 2. The paste charges fired in Test Series 1 had been in storage for 10 days, and some had been transported to and from the test site several times. Because the yields were somewhat

14. Little, Inc., op. cit.

erratic, the exudation and loss of oil as well as possible disruption of charge symmetry during storage and handling was thought to have produced lower yields. Consequently, 16 additional similar paste charges were loaded at the test site and immediately fired. Although the statistical analysis determined there was no significance in any of the variables, a comparison of the yields for Test Series 1 and 2 showed the yields from Test Series 2 charges were more consistent and greater for 5 out of the 8 charge groups of similar design parameters (Table V). The differences in yields were not significantly greater, but the results were less erratic in Test Series 2.

Table V. Comparison of Yields for Paste Charges in Test Series 1 and 2

Stand-off (in.)	Cone Type*	Loaded Height Above Vertex (in.)	Test Series 1: Average Penetration Depth (in.)	Test Series 1: Average Penetration Volume (in.)	Test Series 2: Average Penetration Depth (in.)	Test Series 2: Average Penetration Volume (in.)
5	M	2-1/2	10.8	5.0	10.1	3.3
5	M	1-3/4	10.4	4.4	7.0	3.0
5	HF	2-1/2	9.8	5.0	9.2	3.0
9	HF	2-1/2	8.6	3.5	9.7	4.9
9	M	1-3/4	7.6	3.3	10.7	4.4
9	M	2-1/2	7.0	3.3	8.4	3.4
5	HF	1-3/4	6.9	3.4	8.9	4.3
9	HF	1-3/4	4.2	2.8	10.3	5.0

* The letters "M" and "HF" signify machined and hand-formed cones, respectively.

14. Evaluation of Improvised Shaped Charges. The method of fabricating shaped charges covered in this report is considered feasible for field use by engineer troops. Combat engineer battalions are issued both a motorized machine shop and a Blacksmith Equipment Set, each containing the necessary tools for fabricating improvised shaped charge components. Sheet steel, copper, aluminum, etc., are stock items in Engineer Supply Points, and, although special skill is not required in hand-forming the shaped charge components, mechanically trained personnel are available, if necessary.

The possible uses to which improvised shaped charges may be applied are numerous. At present, the standard M2A3 and M3 shaped charges are used primarily to produce boreholes in steel, concrete, rock, masonry, and earth. However, their most common field use is producing boreholes in earth to receive explosive charges for antitank cratering. Other less common applications include blasting of boreholes in fortifications to receive secondary charges for destruction of the fortifications and their use as antitank and antipersonnel mines in defiles and likely forward landing areas. Improvised shaped charges could be used to supplement or replace the manufactured charges in any of these described demolition tasks.

15. Evaluation of Paste Explosive as a Shaped Charge Filler. This report has shown that paste explosive makes an effective filler for improvised shaped charges. Tests have proved that improvised shaped charges with about 3 pounds of paste explosive and hand-formed liners can reliably produce penetration of 10 to 12 inches in steel. These results are better than those of the standard shaped charge, M2A3, which uses about 11½ pounds of explosive and a glass liner to penetrate 12 inches of steel. The M2A3 shaped charge is also capable of producing boreholes of 5 to 8 feet depth in earth. It is estimated that 5 pounds of paste explosive loaded into an improvised shaped charge with a hand-formed copper liner of about 6 inches base diameter will produce the same or better results.

Paste explosive should also be useful in other field improvised charges such as the bangalore torpedo, mine clearing devices, platter and linear shaped charges, and booby traps. Its use as an explosive filler for improvised charges is more practicable than Composition C-4 because it can be easily and quickly loaded into a charge assembly without loss of density and, thus, loss of power. Conversely, Composition C-4 must be hand-tamped into charge assemblies to avoid loss of density with resulting reduction of effectiveness. The quality of C-4 loading for the tests covered by this report was accomplished by a testman who was highly experienced and exercised extreme care requiring considerable time for each charge. Such personnel and careful preparation of charges will seldom be found or experienced in the field, thus, paste charges prepared by troops will probably yield similar results to C-4 charges prepared under such conditions. The ease of loading and retention of its density and power under loading conditions makes paste explosive readily adaptable to field use in packaged charges. Its characteristic exudation of oil does not significantly affects its power, and its insensitivity will not be a problem with the introduction of the M6 and M7 blasting caps to field use. As an effective military explosive, the attributes of paste explosive outweigh its deficiencies. Paste explosive has potentiality as an explosive filler for improvised charges.

IV. CONCLUSIONS

16. Conclusions. It is concluded that:

a. Paste explosive is an effective explosive filler for improvised shaped charges.

b. Precision manufactured shaped charge liners produce greater and more reliable yields than hand-formed liners, but hand-formed liners afford yields acceptable for general demolition tasks requiring the use of shaped charges.

c. For improvised shaped charges, paste explosive is almost as good as Composition C-4 explosive in most qualities and better in ease of loading; other military explosives being solid are not readily adaptable to improvised shaped charges.

d. Field fabrication and use of improvised shaped charges is feasible.

e. Additional borehole penetration tests should be conducted in various materials, especially concrete and asphaltic pavements, to obtain complete data relative to the usefulness of improvised shaped charges.

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PASD (PA)
Targets references not available to general public

APPENDICES

APPENDIX A

AUTHORITY

HEADQUARTERS
DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON 25, D. C.

READ FOR RECORD
Item Nr. 1357
CETC Mtg. #317

ENGRD-P

1 July 1960

SUBJECT: Demolitions, Project Nr. 8F07-10-002, Reopening of Task Nr. 8F07-10-002-02, DEMOLITION MATERIAL AND EQUIPMENT

TO: Corps of Engineers Technical Committee

FROM: Acting Secretary, Corps of Engineers Technical Committee

1. References:

a. Item Nr. 2859, CETC Meeting Nr. 295.

b. Item Nr. 3077, CETC Meeting Nr. 312.

2. Subproject 8-07-10-460, Demolition Material and Equipment was suspended by reference 1a above. Subproject 8-07-10-460, was changed to Task Nr. 8F07-10-002-02, Demolition Material & Equipment by reference 1b, above. This task is hereby restored to an active status, FY 1961 RDT&E funds having been allocated for the prosecution thereof.

3. This action will be recorded in the minutes of the Corps of Engineers Technical Committee.

/s/ Roy C. Cornett
/t/ ROY C. CORNETT
Acting Secretary, Corps of
Engineers Technical Committee

HEADQUARTERS
DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON 25, D. C.

Item No. 3077
CETC Mtg. #312

ENGNE

1 February 1960

SUBJECT: DEMOLITIONS, Project No. 8F07-10-002, Initiation of Project

TO: Corps of Engineers Technical Committee

FROM: Subcommittee on Mine Warfare

1. The Subcommittee presents the proposed project in the field of Demolitions, as described in the inclosed Form DD 613, for appropriate action by the Corps of Engineers Technical Committee.

2. The project will consist of the tasks as listed in paragraph 21c of the inclosure. The existing tasks are identified by the Item Number preceding the Task Number. Those preceded by the words "New Item" are proposed, and will be processed at the earliest possible date.

3. The Subcommittee recommends:

a. Initiation of Project No. 8F07-10-002, Demolitions, and assignment to the Corps of Engineers.

b. Assignment of Technical Objective LC-13 to the Project.

c. Assignment of Priority 1-B to the Project.

FOR THE SUBCOMMITTEE:

1 Incl
Project No. 8F07-10-002

/s/ H. D. Ford
/t/ H. D. FORD
Lt. Colonel, Corps of Engineers
Chairman, Subcommittee on
Mine Warfare

Item No. 3077
CETC Mtg # 312

R & D PROJECT CARD | TYPE OF REPORT: New | REPORT CONTROL SYMBOL: CSCRD-1(R1)

1. PROJECT TITLE	DEMOLITIONS
2. SECURITY OF PROJECT	Unclassified
3. PROJECT NO.	8707-10-002
4. INDEX NUMBER	——
5. REPORT DATE	1 Feb 1960
6. BASIC FIELD OR SUBJECT	Mines and Obstacles
7. SUB FIELD OR SUBJECT SUB GROUP	Fortifications, Obstacles & Demolitions
7A. TECH. OBJ.	LC-13
8. COGNIZANT AGENCY	Corps of Engineers
9. DIRECTING AGENCY	Res. & Dev. Div., OCE
10. REQUESTING AGENCY	Office, Chief of Engineers
11. PARTICIPATION AND/OR COORDINATION	
12. CONTRACTOR AND/OR LABORATORY	USA Engr. Res. & Dev. Labs., Ft. Belvoir, Va.
CONTRACT/W. O. NO.	
13. RELATED PROJECTS	
14. DATE APPROVED	
15. PRIORITY	1-B
16. MAJOR CATEGORY	

17. EST. COMPLETION DATES	
RES.	Cont.
DEV.	Cont.
TEST	Cont.
OP. EVAL.	Cont.

18. FY.	FISCAL ESTIMATES
60	5 M
61	45 M
62	35 M
Est.	Rate P/A 35 M

19. REPLACED PROJECT CARD AND PROJECT STATUS
This project supersedes part of Project No. 8-07-10-000, 31 December 1959.

20. REQUIREMENT AND/OR JUSTIFICATION – There is a continuing requirement for development of new or improved equipment in the field of demolitions.

Justification for the development of each piece of equipment, with appropriate CDOG references, is included in the Task Cards as listed in paragraph 21c below.

21. BRIEF OF PROJECT AND OBJECTIVE

a. Brief:

(1) Objective:

(a) To provide for the conduct of the research and development necessary to supply required equipment to the Army, and to the other Departments as may be required and authorized, in the field of demolitions.

(b) The security classification of the individual tasks of this project will be in accordance with their content.

(2) Military Characteristics: The Military Characteristics for each item being developed are included as Exhibits "A" to each of the Task Cards as listed in paragraph 21c below.

22. OASD (R & D)	BN.	CN.	C.	R.	I.	C.

DD FORM 1 APR 55 613 — PAGE 1 OF 2 PAGES
REPLACES DD FORM 613, 1 JAN 52.

54

R&D PROJECT CARD
CONTINUATION SHEET

Item No. 3077
CETC Mtg. # 312

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
DEMOLITIONS	Unclassified	8F07-10-002
	4. ——	5. REPORT DATE 1 Feb 1960

b. Approach: The approach to each task is set forth in the Task Cards as listed in paragraph 21c below.

c. Tasks: This project is composed of the tasks as listed herein. The completion of tasks and the establishment of new tasks will be recorded by the revision of this paragraph.

(1) Item No. 3054, Task No. 8F07-10-002-01, Engineering Studies & Investigations, Demolitions.

(2) Item No. 1357, Task No. 8F07-10-002-02, Demolition Material & Equipment (Suspended).

d. Other Information:

(1) Scientific Research: None

(2) References: None

DD FORM 1 FEB 56 613-1
REPLACES DD FORM 613-1, 1 FEB 56.

APPENDIX B

STATISTICAL ANALYSIS FOR PENETRATION OF STEEL PLATES BY SHAPED CHARGES

by

Richard E. Deighton

The two sets of test data were analyzed separately. First, the various statistical analyses on the first set of data will be discussed, and then the second set of data will be similarly treated.

The first test was designed as a complete factorial experiment with four factors. All factors were observed at two levels with three replicates of the experiment. The following notation will be used for the factors:

A, height of explosive above vertex of cone.
Level 1 - 3-3/4 inches.
Level 2 - 2-1/2 inches.

B, type of cone.
Level 1 - machined.
Level 2 - improvised.

C, standoff distance.
Level 1 - 5 inches.
Level 2 - 9 inches.

D, type of explosive.
Level 1 - C-4.
Level 2 - paste.

The test was also designed to utilize the principle of confounding. A complete confounding of the highest order interaction, that is the third order interaction ABCD, was made. This means that each of the three replicates was split into two blocks, each block consisting of eight observations.

The depths of the penetrations in inches were used as the first measurement of yield for this experiment. An analysis of variance was calculated both without confounding (Table VI) and with confounding (Table VII). In both analyses, the F's were calculated by dividing the mean squares of the effects by the mean square of the experimental error. Note that identical interpretations are derived from both analyses. In addition, the analysis of variance for confounding indicates that there is no significant contribution due to block variation. This result most likely indicates that each steel plate is homogeneous with respect to itself. Another plausible interpretation of this result is that the steel plates were placed on the ground in such a manner that no differences among various sides of the steel plates existed.

Of the various main effects, only the type of cone and the type of explosive were shown to be significant. That is, no significance was indicated in either the height of the explosive above the vertex of the cone or the standoff distance. Two of the first order interactions were found to be significant. These are the interaction of type of explosive with the height of the explosive above the vertex of the cone and the interaction of type of explosive with standoff distance. These interactions appear to be significant because the type of explosive is highly significant itself. Also, there is one significant second order interaction. This is the interaction among height above vertex of cone, type of cone, and type of explosive. The high significance of type of explosive is apparently causing this interaction to be significant also.

After these analyses were conducted, the volumes of the penetrations were calculated. The assumption was made that a penetration within a given plate was approximately cylindrical. Consequently, the volume of a given hole was calculated as the summation of a set of cylindrical volumes for all the plates that were penetrated.

These volumes were then used as a second measurement of yield. Again, an analysis of variance was conducted both without confounding (Table VIII) and with confounding (Table IX). Again both of these two analyses indicated the same results. The only effect that was found to be significant using volumes was the type of explosive. No interactions were found to be significant. The analyses with confounding again indicated that there was no significant block variation. As with the depths, this result apparently indicates that each steel plate is homogeneous with respect to itself.

In comparing depths and volumes as measurements of yield, the main difference seems to be that with depths the type of explosive interacts with the distances whereas this is not true with volumes used as the measurement of yield. Perhaps in theoretical mechanics there is a justification for this difference.

The second set of test data was designed as a complete factorial experiment with three factors, using paste throughout. These three factors were all observed at two levels with two replicates of the experiment. The following notation will be used for the factors:

A, height of explosive above vertex of cone.
Level 1 - 1-3/4 inches.
Level 2 - 2-1/2 inches.

B, type of cone.
Level 1 - machined.
Level 2 - improvised.

C, standoff distance.
Level 1 - 5 inches.
Level 2 - 9 inches.

Again, the test was designed to utilize the principle of confounding. A complete confounding of the highest order interaction, that is the second order interaction ABC, was made. This means that each of the two replicates was split into two blocks, each block consisting of four observations.

First, the depths of the penetrations in inches were used as the measurement of yield. The analysis of variance on these depths (Table X) indicates that there is no significance in any of the main effects or interactions. Although the F ratio for the ABC interaction was not significant, it was larger than most of the other F ratios. Since this interaction was confounded with blocks, it was not considered worthwhile to compute an analysis of variance with confounding.

Next, the volumes of the penetrations were calculated. The analysis of variance on this data (Table XI) indicates that the type of cone and the standoff distance are significant. Also, the interaction of these two factors was discovered to be significant. An analysis of variance with confounding was then calculated (Table XII). As in the first set of test data, the block variation was not significant. The type of cone, the standoff distance, and the interaction of these two factors showed only a slight significance whereas stronger significance was indicated in the first analyses.

All the analysis of variance tables indicated above do not have exactly the same interpretations, but it is possible to derive some general interpretations. Type of explosive and type of cone are reasonably significant factors in the experiments whereas the distances do not appear to be significant. The calculations for confounding in blocks indicate that there is no significant variation from one side of the steel plates to the other side.

Table VI. Analysis of Variance Without Confounding for Depths from Test Series 1

Effects	Calculated F's	Tabular F's: Degrees of Freedom*	90%	95%	99%
A	$\frac{4.53}{3.12} = 1.45$	1/32	2.88	4.17	7.56
B	$\frac{27.03}{3.12} = 8.66^{(3)}$	"	"	"	"
C	$\frac{0.81}{3.12} = 0.26$	"	"	"	"
D	$\frac{216.67}{3.12} = 69.45^{(3)}$	"	"	"	"
AB	$\frac{6.01}{3.12} = 1.93$	"	"	"	"
AC	$\frac{0.04}{3.12} = 0.01$	"	"	"	"
AD	$\frac{16.73}{3.12} = 5.36^{(2)}$	"	"	"	"
BC	$\frac{4.15}{3.12} = 1.33$	"	"	"	"
BD	$\frac{0.02}{3.12} = 0.01$	"	"	"	"
CD	$\frac{100.23}{3.12} = 32.125^{(3)}$	"	"	"	"
ABC	$\frac{2.02}{3.12} = 0.65$	"	"	"	"
ABD	$\frac{16.40}{3.12} = 5.26^{(2)}$	"	"	"	"
ACD	$\frac{0.00}{3.12} = 0.00$	"	"	"	"
BCD	$\frac{0.06}{3.12} = 0.02$	"	"	"	"
ABCD	$\frac{0.47}{3.12} = 0.15$	"	"	"	"

A = Distance above vertex of cone.
B = Type of cone.
C = Standoff distance.
D = Type of explosive.

*30 d.f. was actually used.
(1) Slightly significant.
(2) Significant.
(3) Highly significant.

Table VII. Analysis of Variance with Confounding for Depths from Test Series 1

Effects	Calculated F's	Tabular F's			
		Degrees of Freedom*	90%	95%	99%
A	$\frac{4.53}{3.41} = 1.33$	1/28	2.88	4.17	7.56
B	$\frac{27.03}{3.41} = 7.93^{(3)}$	"	"	"	"
C	$\frac{0.81}{3.41} = 0.24$	"	"	"	"
D	$\frac{216.67}{3.41} = 63.54^{(3)}$	"	"	"	"
AB	$\frac{6.01}{3.41} = 1.76$	"	"	"	"
AC	$\frac{0.04}{3.41} = 0.01$	"	"	"	"
AD	$\frac{16.73}{3.41} = 4.91^{(2)}$	"	"	"	"
BC	$\frac{4.15}{3.41} = 1.22$	"	"	"	"
BD	$\frac{0.02}{3.41} = 0.01$	"	"	"	"
CD	$\frac{100.23}{3.41} = 29.39^{(3)}$	"	"	"	"
ABC	$\frac{2.02}{3.41} = 0.59$	"	"	"	"
ABD	$\frac{16.40}{3.41} = 4.81^{(2)}$	"	"	"	"
ACD	$\frac{0.00}{3.41} = 0.00$	"	"	"	"
BCD	$\frac{0.06}{3.41} = 0.02$	"	"	"	"
Blocks	$\frac{0.96}{3.41} = 0.28$	5/28	2.05	2.53	3.70

A = Distance above vertex of cone.
B = Type of cone.
C = Standoff distance.
D = Type of explosive.

*30 d.f. was actually used.
(1) Slightly significant.
(2) Significant.
(3) Highly significant.

Table VIII. Analysis of Variance Without Confounding for Volumes from Test Series 1

Effects	Calculated F's	Tabular F's			
		Degrees of Freedom*	90%	95%	99%
A	$\frac{5.43}{1.73} = 3.14^{(1)}$	1/32	2.88	4.17	7.56
B	$\frac{5.84}{1.73} = 3.38^{(1)}$	"	"	"	"
C	$\frac{3.75}{1.73} = 2.17$	"	"	"	"
D	$\frac{43.59}{1.73} = 25.20^{(3)}$	"	"	"	"
AB	$\frac{0.74}{1.73} = 0.43$	"	"	"	"
AC	$\frac{0.14}{1.73} = 0.08$	"	"	"	"
AD	$\frac{0.05}{1.73} = 0.03$	"	"	"	"
BC	$\frac{1.86}{1.73} = 1.08$	"	"	"	"
BD	$\frac{1.90}{1.73} = 1.10$	"	"	"	"
CD	$\frac{6.02}{1.73} = 3.48^{(1)}$	"	"	"	"
ABC	$\frac{0.81}{1.73} = 0.47$	"	"	"	"
ABD	$\frac{0.56}{1.73} = 0.32$	"	"	"	"
ACD	$\frac{0.59}{1.73} = 0.34$	"	"	"	"
BCD	$\frac{0.63}{1.73} = 0.36$	"	"	"	"
ABCD	$\frac{0.27}{1.73} = 0.16$	"	"	"	"

A = Distance above vertex of cone.
B = Type of cone.
C = Standoff distance.
D = Type of explosive.

*30 d.f. was actually used.
(1) Slightly significant.
(2) Significant.
(3) Highly significant.

Table IX. Analysis of Variance With Confounding for Volumes from Test Series 1

Effects	Calculated F's	Tabular F's: Degrees of Freedom*	Tabular F's: 90%	Tabular F's: 95%	Tabular F's: 99%
A	$\frac{5.43}{1.90} = 2.86$	1/28	2.88	4.17	7.56
B	$\frac{5.84}{1.90} = 3.07$ (1)	"	"	"	"
C	$\frac{3.75}{1.90} = 1.97$	"	"	"	"
D	$\frac{43.59}{1.90} = 22.94$ (3)	"	"	"	"
AB	$\frac{0.74}{1.90} = 0.39$	"	"	"	"
AC	$\frac{0.14}{1.90} = 0.07$	"	"	"	"
AD	$\frac{0.05}{1.90} = 0.03$	"	"	"	"
BC	$\frac{1.86}{1.90} = 0.98$	"	"	"	"
BD	$\frac{1.90}{1.90} = 1.00$	"	"	"	"
CD	$\frac{6.02}{1.90} = 3.17$ (1)	"	"	"	"
ABC	$\frac{0.81}{1.90} = 0.43$	"	"	"	"
ABD	$\frac{0.56}{1.90} = 0.29$	"	"	"	"
ACD	$\frac{0.59}{1.90} = 0.31$	"	"	"	"
BCD	$\frac{0.63}{1.90} = 0.33$	"	"	"	"
Blocks	$\frac{0.51}{1.90} = 0.27$	5/28	2.05	2.53	3.70

A = Distance above vertex of cone.
B = Type of cone.
C = Standoff distance.
D = Type of explosive.

*30 d.f. was actually used.
(1) Slightly significant.
(2) Significant.
(3) Highly significant.

Table X. Analysis of Variance Without Confounding for Depths from Test Series 2

Effects	Calculated F's	Tabular F's			
		Degrees of Freedom	90%	95%	99%
A	$\frac{0.04}{4.30} = 0.01$	1/8	3.46	5.32	11.3
B	$\frac{0.77}{4.30} = 0.18$	"	"	"	"
C	$\frac{3.42}{4.30} = 0.80$	"	"	"	"
AB	$\frac{0.29}{4.30} = 0.07$	"	"	"	"
AC	$\frac{9.80}{4.30} = 2.28$	"	"	"	"
BC	$\frac{0.00}{4.30} = 0.000$	"	"	"	"
ABC	$\frac{5.24}{4.30} = 1.22$	"	"	"	"

A = Distance above vertex of cone.
B = Type of cone.
C = Standoff distance.

(1) Slightly significant.
(2) Significant.
(3) Highly significant.

Table XI. Analysis of Variance Without Confounding for Volumes from Test Series 2

Effects	Calculated F's	Tabular F's: Degrees of Freedom	90%	95%	99%
A	$\frac{2.15}{2.96} = 0.73$	1/8	3.46	5.32	11.3
B	$\frac{15.78}{2.96} = 5.33$(2)	"	"	"	"
C	$\frac{22.35}{2.96} = 7.55$(2)	"	"	"	"
AB	$\frac{3.92}{2.96} = 1.32$	"	"	"	"
AC	$\frac{8.03}{2.96} = 2.71$	"	"	"	"
BC	$\frac{16.53}{2.96} = 5.58$(2)	"	"	"	"
ABC	$\frac{5.38}{2.96} = 1.82$	"	"	"	"

A = Distance above vertex of cone.
B = Type of cone.
C = Standoff distance.

(1) Slightly significant.
(2) Significant.
(3) Highly significant.

Table XII. Analysis of Variance With Confounding for Volumes from Test Series 2

Effects	Calculated F's	Tabular F's			
		Degrees of Freedom	90%	95%	99%
A	$\frac{2.15}{4.01} = 0.54$	1/6	3.78	5.99	13.7
B	$\frac{15.78}{4.01} = 3.94^{(1)}$	"	"	"	"
C	$\frac{22.35}{4.01} = 5.57^{(1)}$	"	"	"	"
AB	$\frac{3.92}{4.01} = 0.98$	"	"	"	"
AC	$\frac{8.03}{4.01} = 2.00$	"	"	"	"
BC	$\frac{16.53}{4.01} = 4.12^{(1)}$	"	"	"	"
Blocks	$\frac{1.68}{4.01} = 0.42$	3/6	3.29	4.76	9.78

A = Distance above vertex of cone.
B = Type of cone.
C = Standoff distance.

(1) Slightly significant.
(2) Significant.
(3) Highly significant.

Category 13 - Mine Warfare and Demolitions

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TITLE Improvised Shaped Charges with Paste Explosive Filler

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U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia - IMPROVISED SHAPED CHARGES WITH PASTE EXPLOSIVE FILLER - James A. Dennis

Report 1710-TR, 19 Mar 62, 64 pp, 26 illus, 12 tables
DA Task 8F07-10-002-02 Unclassified Report

Report covers tests conducted to determine effectiveness of RDX base paste explosive as explosive filler for improvised shaped charges. Performance of hand-formed and precision manufactured cavity liners was also evaluated. Shaped charge parameters investigated were: Type of explosive filler, explosive loaded height above liner vertex, type of conical liner, and standoff distance. Tests performed were designed as a full factorial experiment, and results were analyzed by analysis of variance. Seventy-four improvised shaped charges were fabricated in the field and fired into a target stack of steel plates. Measurements were recorded of depths of penetration and volumes of resulting holes in target. A controlled comparison was made of shaped charges loaded with Composition C-4 and shaped charges loaded with paste as well as other charge variables tested. Report concludes: (a) Paste explosive is an effective explosive filler for improvised shaped charges; (b) precision manufactured shaped charge liners produce greater and more reliable yields than hand-formed liners, but hand-formed liners afford yields acceptable for general demolition tasks requiring use of shaped charges; (c) for improvised shaped charges, paste explosive is almost as good as Composition C-4 explosive in most qualities and better in ease of loading; other military explosives being solid are not readily adaptable to improvised shaped charges; (d) field fabrication and use of improvised shaped charges is feasible; and (e) additional borehole penetration tests should be conducted in various materials, especially concrete and asphaltic pavements, to obtain complete data relative to usefulness of improvised shaped charges.

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